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BOTTOM TEMPERATURE MEASUREMENTS IN PROSPECT HARBOR,
SUPPLEMENT [redacted] 1 AND 2 TO A PRELIMINARY DESIGN,
ECONOMIC AND ENERGY ANALYSIS, AND ENVIRONMENTAL
IMPACT ASSESSMENT FOR A SEAWATER COOLING PROJECT,
NAVAL SECURITY GROUP FACILITIES AT WINTER HARBOR,
MAINE.

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An Investigation Conducted by
TRACOR MARINE
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Maximum seawater temperatures were measured on the bottom of Prospect Harbor which adjoins the Corea, ME, detachment of NSGA Winter Harbor, ME, from July to October at two water depths. At a water depth of 45 feet the average temperature reached 50°F near the end of July and remained above 50°F until the end of the measurements in October. Higher temperature transients ex-

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AND ENERGY ANALYSIS, AND ENVIRONMENTAL IMPACT ASSESSMENT FOR A SEAWATER COOLING PROJECT NAVAL SECURITY GROUP FACILITIES AT WINTER HARBOR, MAINE; BIOFOULING AND ITS PREVENTION IN PROSPECT HARBOR, SUPPLEMENT NO. 2, TO A PRELIMINARY DESIGN, ECONOMIC & ENERGY ANALYSIS, AND ENVIRONMENTAL IMPACT ASSESSMENT FOR A SEAWATER COOLING PROJECT NAVAL SECURITY GROUP FACILITIES AT WINTER HARBOR, MAINE

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ceeding 53°F occurred in August and early September for several hours; the highest of these was 55.8°F. At a water depth of 20 feet the temperatures were several degrees higher until early September, when the temperatures at the shallower location closely followed those of the deeper. It was concluded regarding the NSGA Winter Harbor seawater air conditioning (AC) system that (1) enhancement is required during the hottest weather, (2) reduction in the heat gain is desirable and (3) the seawater intake should be at the deeper location (45-50 feet).

A detailed examination was made of the biofouling community in Prospect Harbor, the NSGA seawater AC system components which are sensitive to biofouling, and biofouling countermeasure systems. It was concluded that: (1) this system must cope with a serious biofouling problem, (2) a seawater well sunk into the bottom sediments could be used as the seawater intake and would provide the most suitable solution to this problem, (3) sufficient sediment thickness is available for such a well but it is not certain whether the sediments in the intake area can support the required flow (permeability), and (4) copper-nickel alloy tubing or ultraviolet treatment may be required to supplement the seawater well.

FOREWORD

This work is a continuation of Contract No. N68305-77-C-0012 with the Energy Programs Office of the U.S. Navy Civil Engineering Laboratory in Port Hueneme, California. The purpose of this work is to determine actual bottom temperatures in Prospect Harbor, Maine, to support the design of a direct seawater building cooling system at the Naval Security Facility, Corea, Maine.

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I. INTRODUCTION

A preliminary design[1] for a proposed direct seawater cooling system for a building in the Naval Security Facility, Corea, Maine, was performed in early 1977. Seawater, drawn from the bottom of Prospect Harbor, is thought to be cold enough to be circulated directly through special chiller coils of an air-conditioning system, eliminating the use of conventional vapor compression chillers, and thereby saving about 70 percent of the energy used for air conditioning.

Since no seawater temperature measurements were available for Prospect Harbor, data from other bays along the Maine coast was extrapolated to Prospect Harbor. A maximum seawater temperature of 53°F was used in the design and evaluation of the proposed system.

This seawater temperature impacts the design of the cooling system in several important ways.

1. The temperature of the chilled water delivered to the air-conditioning coils determines (a) the size and configuration of the coils and the air flow required to meet room design conditions, and (b) the amount of supplemental dehumidification required, if any, to meet room design conditions.

2. The selection of the seawater/chilled water heat exchanger characteristics (LMTD) depends on the temperature of the

[1] "A Preliminary Design, Economic & Energy Analysis, and Environmental Impact Assessment for a Seawater Cooling Project, Naval Security Group Facilities at Winter Harbor, Maine, Final Report," Tracor Marine, Inc., March 1977.

seawater. For example, in the Corea project the heat exchanger would be completely eliminated and the seawater routed directly to the chiller coils, if the seawater temperature is above 50°F.

3. The design factors affecting heat gain in the seawater pipeline, such as (a) insulating characteristics of the pipe, (b) burial depth, and (c) seawater flow.

4. The location and design of the seawater intake to obtain the lowest temperature seawater possible.

5. Finally, the sum of the above design considerations determines whether direct seawater cooling of buildings at the site in question is a suitable alternate to conventional air conditioning.

Because the seawater temperature does impact the design of the system so significantly, it was necessary to determine the actual bottom temperatures in Prospect Harbor. Several recording thermographs were installed in the bay, and bottom temperatures were recorded during the summer of 1977 (end of May to early October). This report presents the results of these measurements, and briefly discusses their impact on the preliminary design.

II. FIELD PROGRAM

Seawater temperature measurements made in Penobscot Bay during other years by the Central Maine Power Company showed that maximum bottom temperatures occur during the first half of September. Our field program was designed to encompass the summer period (largest air-conditioning load) and the period of maximum bottom temperatures.

Two General Oceanics Model 6070 digital recording thermographs (Appendix I) were obtained and installed about three feet off the bottom at two different locations (depths) along the proposed pipeline route. Appendix II illustrates the mooring configuration. The first was installed in about 45 feet of water approximately 1300 feet from shore. The second was installed in 20 feet of water, approximately 700 feet from shore. Appendix III of this report shows the location of the devices relative to the pipeline survey.

The deepest instrument is located just off the submarine slope, at the start of the flat basin part of the bay. The shallow instrument is about halfway down the slope. The purpose of the shallow instrument is to determine if there is any significant difference between the water temperatures at the two locations. The pipeline could be shortened if the differences were small.

Although the General Oceanics thermographs are designed to record for the entire scheduled field program without change of batteries or magnetic cassettes, we serviced the instruments

after about two months to make sure they were functioning properly before the critical period. Batteries and data tapes were replaced and the instruments were reinstalled. As a further check, and to provide redundancy during the warmest period, a Ryan analog temperature recorder was borrowed from the Central Maine Power Company and installed on the deep moor during the last two weeks in August and the first two weeks in September. This instrument has only a two-week endurance and had to be serviced after the first two weeks.

Field Measurement Schedule

1977	May	Jun	Jul	Aug	Sep	Oct
Gen. Oceanics Thermographs (2)	5/30 ▽ ----	----------	---- 7/24 ◇ ----	----------	----------	---- △ 10/8
Ryan Thermograph (1)				8/13 ▽ --- 8/27 ◇	---- △ 9/10	

▽ install

△ remove

◇ service

III. RESULTS

Figures 1 and 2 illustrate data printouts of the deep and shallow thermographs for the same period of time.

A. Deep Thermograph (45 Foot Depth)

The record for the period May 30 through September 9 showed a gradual increase of the average temperature from 45.5^{O}F to almost 53.0^{O}F. During this period the temperature varies approximately 2 degrees over what appears to be a tidal cycle (semi-diurnal). Larger random temperature increases of about 3.5^{O}F occur less frequently and last for several hours. These may be associated with wind changes that cause short-term downwellings.

A maximum temperature of 55.8^{O}F was recorded in early September, but this was a transient event that raised the temperature about 4^{O}F above average for about six hours.

From September 9 through the end of our recording period, the temperature record became much quieter. Average variations were less than one degree. The average temperature reduced gradually to about 52^{O}F by the end of the recording period (October 8).

The Ryan thermograph independently confirmed the average temperatures at the deep location for the four weeks it was in place.

B. Shallow Thermograph (20 Foot Depth)

Average temperatures at this location generally followed the deeper trends but were 2 to 4^{O}F warmer and showed greater variability. Variations of 3-5^{O}F were common, with occasional tran-

sient increases of 7^{o}F observed. The maximum temperature on this trace was 60^{o}F, occurring at the end of August for a period of several hours.

The shallow trace exhibited the same quieting as the deep trace after September 9 and follows the deep trace within a degree after that time. This is an indication that temperatures throughout the water column are relatively uniform during this period.

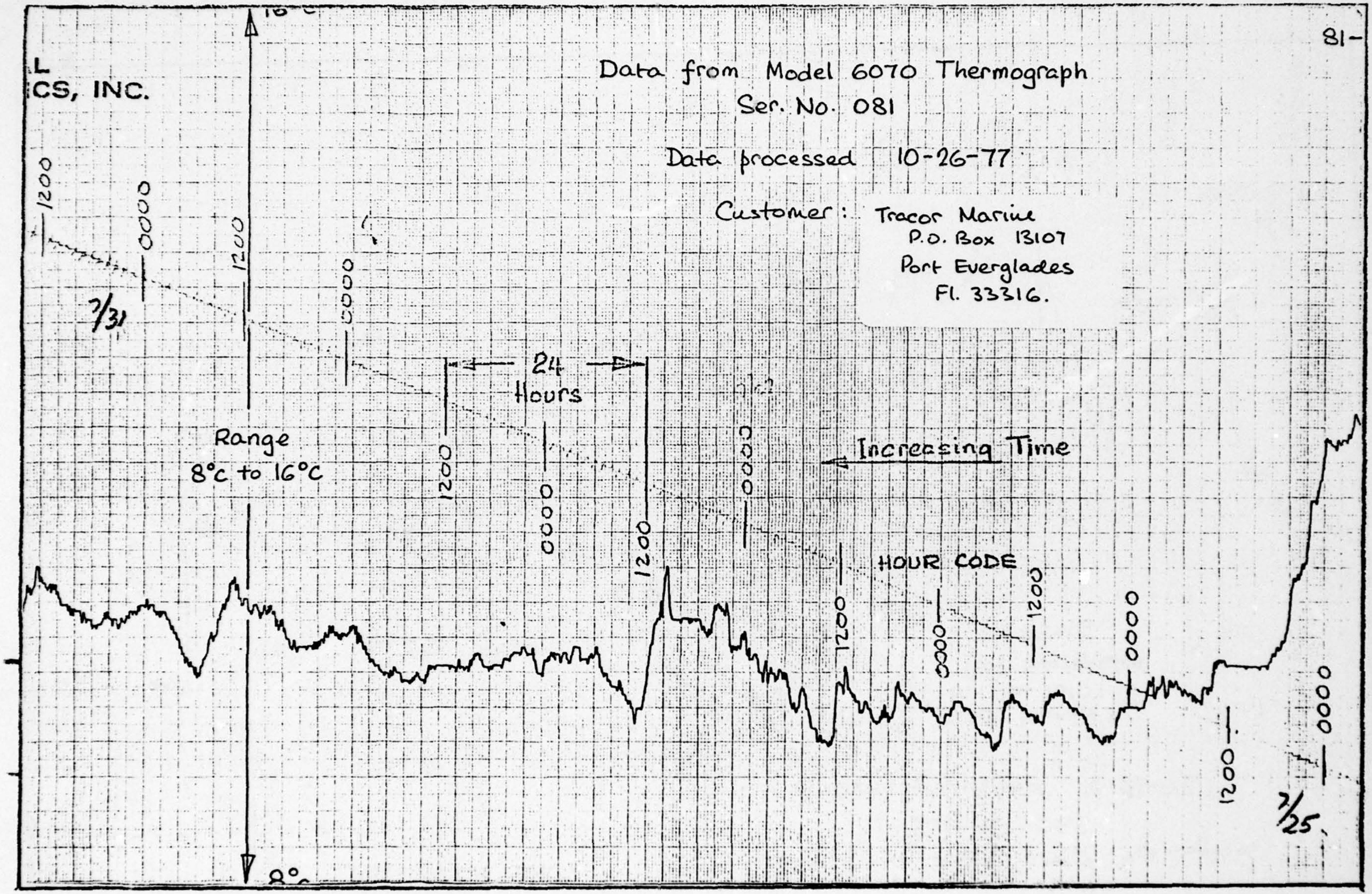

Figure 1. Computer printout of portion of deep temperature trace (45 foot depth).

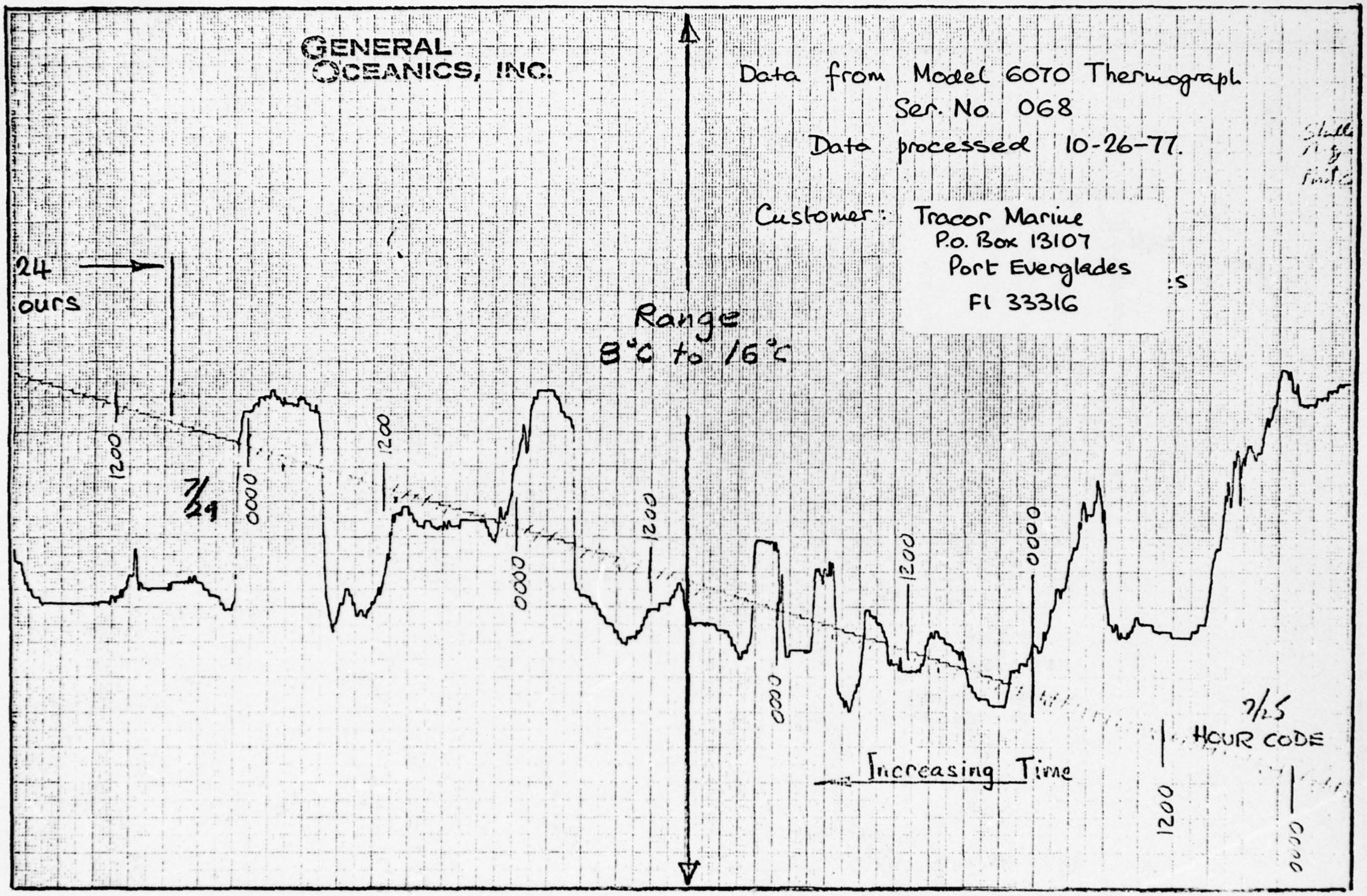

Figure 2. Computer printout of portion of shallow temperature trace (20 foot depth).

IV. SUMMARY AND CONCLUSIONS

A. Summary

Maximum average water temperatures measured on the bottom of Prospect Harbor at a depth of 45 feet are very close to the worst predicted and used in the preliminary design ($53^{O}F$). The average water temperature reached $50^{O}F$ near the end of July and remained above $50^{O}F$ to the end of the measurements in October.

About a dozen transient episodes occurred in August and early September, with the temperature exceeding $53^{O}F$ for several hours, reaching $55.8^{O}F$ during the worst of these.

The temperatures at the 20 foot depth location were on the average several degrees higher than at the deeper level and exhibited wider fluctuations until early September, when the temperatures at the shallow location closely followed those of the deeper.

B. Conclusions

Actual temperature measurements in Prospect Harbor support conservative design decisions made in the Preliminary Design.

1. Additional moisture removal will probably be required during the hottest weather (enhancement).

2. Elimination of the seawater/chilled water heat exchanger to reduce heat gains is desirable.

3. Other efforts to reduce heat gain in the seawater system will be desirable.

4. The seawater intake should be at the deeper location (45-50 feet).

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APPENDIX I

INSTRUMENTATION

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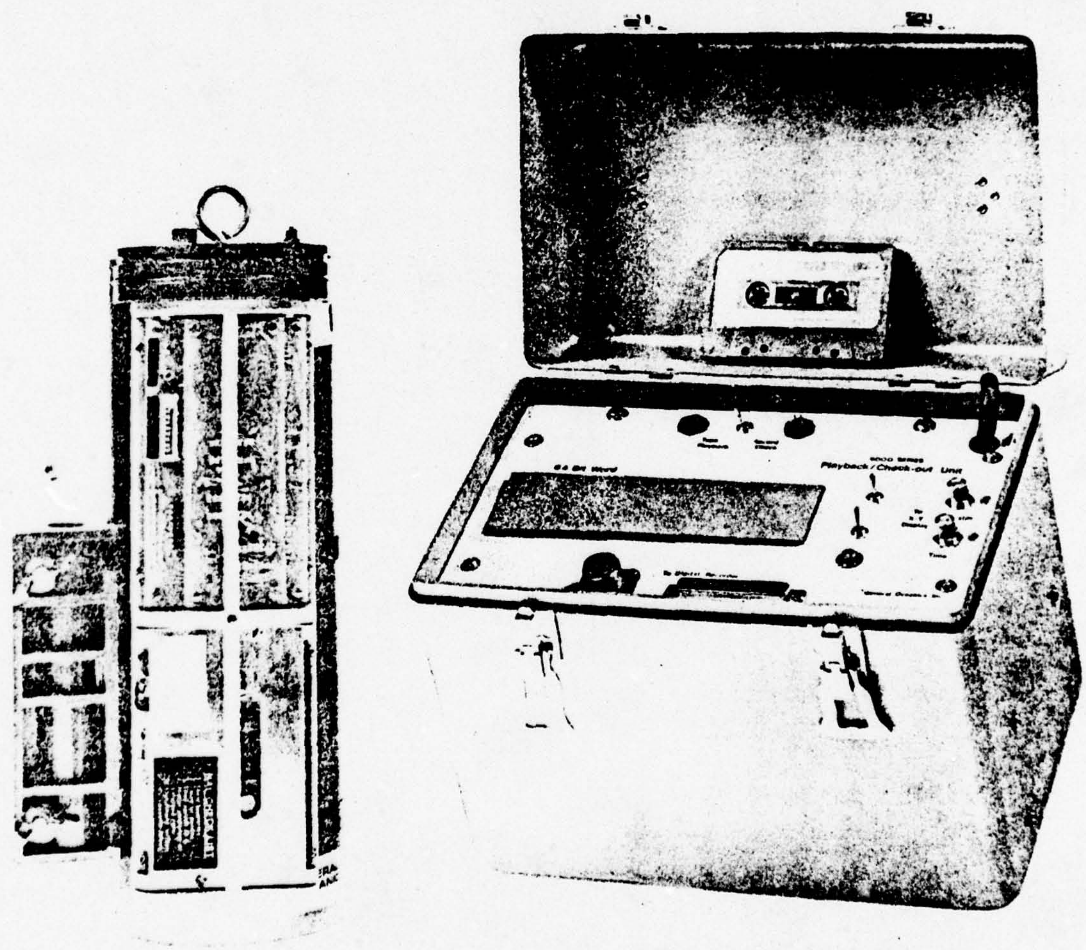
GENERAL OCEANICS

5535 Northwest Seventh Avenue • Miami, Florida 33127 • U.S.A. • Telephone: (305) 754-6658 • Telex 51-9727

CASSETTE TAPE RECORDING DATA SYSTEM

MODEL 6070 THERMOGRAPH & 6000 INTERFAC



Model 6070 Thermograph **Model 6000 Translating Interface** **Pats. Pending**

- Cassette tape recording
- Solid state electronics
- Short or long thermal time constant
- Switch selectable sampling intervals
- Engineered for corrosion free operation
- Light weight

- Tool-free opening & closing of pressure housing
- Clamp-on mounting without separating the mooring line
- One complete electronic translating interface to handle data, carry out pre-deployment operational check, & pinpoint malfunctioning circuitry

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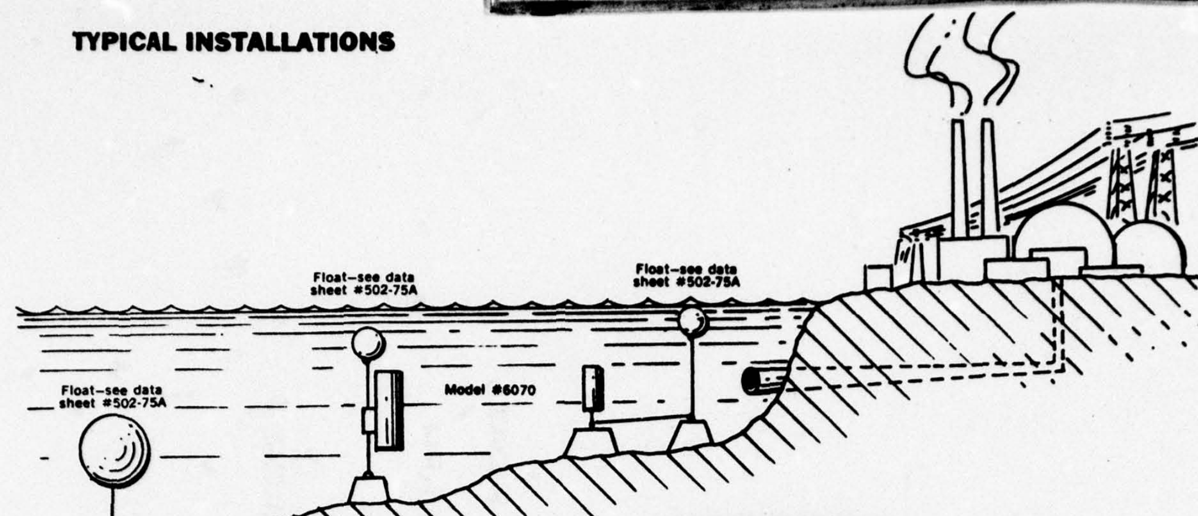
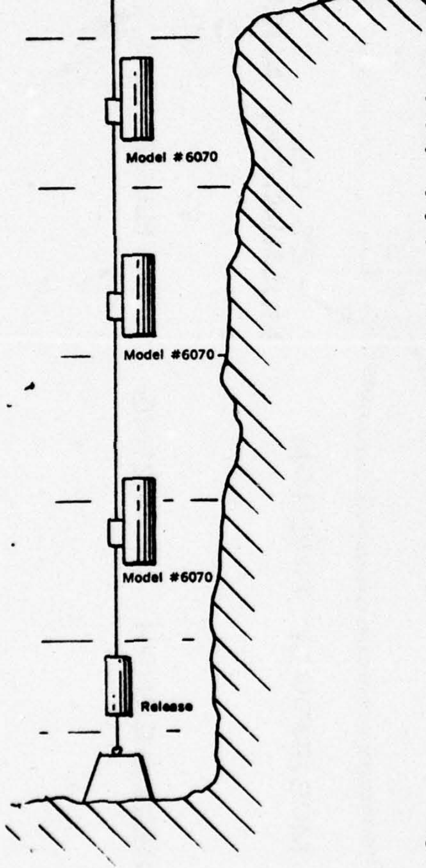
APPENDIX II

MOORING DESCRIPTION

TYPICAL INSTALLATIONS





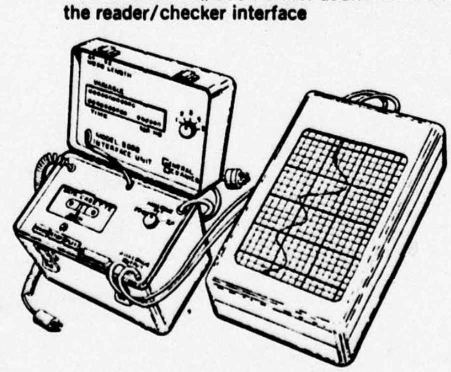
SPECIFICATIONS

Model 6070 Thermograph

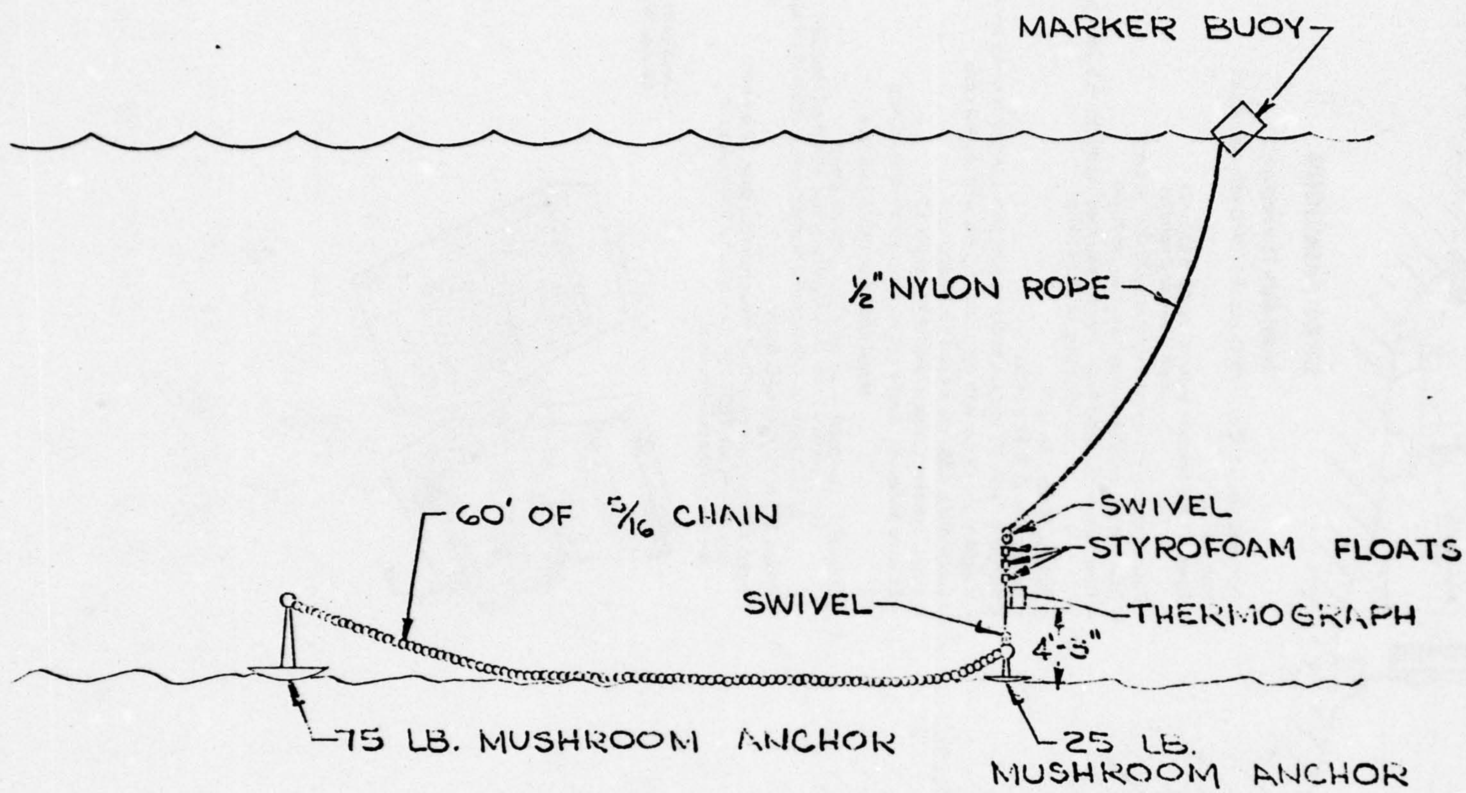
- Temperature: −5°C to +45°C; acc ±1/64°C with calibration
- Stability: .01°C
- Thermal time constant: external sensor 5 seconds
  internal sensor 2 minutes
- Data recording: Phillips style cassette; 25,000 readings
- Data Format: complementary binary on two tracks
- Time Reference: Solid-State crystal controlled oscillator; ±5 sec/day accuracy;
  operating freq. of 18.641 kHz
- Battery: Welded AA cells
- Battery Life: 6 to 12 months
- Sampling Rate: 10 position switch selects from 1 to 512 readings per hour
- Weight in air: 13 lbs. with deep case, 7.5 lbs. with shallow case
- Depth rating: 6000 meters and 50 meters
- Size of pressure casing: diameter 4", length 12"
- Exposed Materials: plastic and hardcoat anodized aluminum

Model 6000 Translating Interface

- Output: 1/ Computer — serial, digital, 384 bit group
  2/ Graphic — two 0-5V signals for use with chart recorders
  3/ LED display — time, serial number, switch selected variable
- Power: 115 or 220 Volts AC, 60 Hz
- Input: Phillips style cassette; 2 track recorded data, 32 bit word
  See Data Sheet #603-75A for additional information on
  the reader/checker interface



Specifications Subject to Change Without Notice



THERMOGRAPH MOORING CONFIGURATION

BIOFOULING AND ITS PREVENTION
IN PROSPECT HARBOR

SUPPLEMENT NO. 2

TO

A PRELIMINARY DESIGN,
ECONOMIC & ENERGY ANALYSIS, AND
ENVIRONMENTAL IMPACT ASSESSMENT

FOR A

SEAWATER COOLING PROJECT
NAVAL SECURITY GROUP FACILITIES IN
WINTER HARBOR, MAINE

FOREWORD

This work is a continuation of Contract No. N68305-77-C-0012 with the Energy Program Office of the U.S. Navy Civil Engineering Laboratory in Port Hueneme, California. The purpose of this work is to:

- Fully assess the biofouling problem in Prospect Harbor as it affects the proposed seawater cooling system,
- Review and catalog equipment and techniques that could be used to prevent and/or remove biofouling in the system,
- Provide recommendations for antifouling equipment and techniques to be incorporated in the final design of the seawater cooling system.

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I. CONCLUSIONS AND RECOMMENDATIONS

A detailed examination was made of:

1. the biofouling community in Prospect Harbor,
2. the system components sensitive to biofouling,
3. the engineering requirements of biofouling countermeasure systems,
4. the biofouling countermeasure systems in common use.

A. Based on this examination and the site information obtained during the offshore survey[5], the following conclusions are reached.

1. The proposed seawater cooling system utilizing bottom water from Prospect Harbor will have to prevent or cope with a serious biofouling problem in the seawater distribution system and the chiller coils, because the waters are rich in fouling organisms and nutrients.

2. A seawater well sunk into the bottom sediments in the intake area could be utilized as the seawater intake and would provide the most suitable solution to the prevention of biofouling in the proposed seawater cooling system.

a) All larvae and larger material would be removed prior to entering any part of the system, virtually eliminating macro-organism colonization.

b) Bacterial populations will be greatly reduced.

c) Low initial cost.

d) No routine maintenance would be required at the intake and intake pipeline (low maintenance costs).

e) Smoothing of transient temperature peaks in the intake water and possible lower intake temperatures during warm periods.

f) No disturbance of organisms in the Bay due to the intake.

3. It is not certain whether the sediments in the intake area can support (permeability) a seawater well with the flow required; however, a sufficient sediment thickness is available for such a well.

4. The seawater well will reduce bacteria but will not remove them completely. Microfouling in the chiller coils might still present a heat transfer efficiency problem. The use of copper-nickel alloy tubing might avert this problem; however, it is possible that ultraviolet treatment of the water prior to entering the coils might be desirable to kill bacteria and other microfouling organisms.

B. Our recommendations are:

1. An analysis of the sediment cores taken earlier[5] in the intake area should be made to determine whether a seawater well is feasible, prior to the final design. If the results of this analysis indicate marginal conditions, a test well should be installed to prove whether this technique can be used.

2. A slow sand filter, depending on wave action to keep the surface clean, is the next best solution; however, it will probably be the most costly if constructed new. If the seawater well is not feasible, the designers should examine the costs of converting an old sand/gravel barge or similar structure into a slow sand filter and sinking it at the site.

3. If some variation of the seawater well or slow sand filter cannot be used, the next best alternative is the use of multiple rapid

sand filters on the positive side of the pumps, with duplicate offshore intake lines to permit alternating treatment (the preliminary design). The number of rapid sand filters used will be determined by backwash requirements (filters can be used in parallel but backwashed one at a time).

4. Chlorine or other chemical treatment of the water to prevent fouling is not recommended as a routine procedure because the intake site is an active lobster fishery.

5. A test of whether ultraviolet treatment is necessary in the final system should be made. One of the chiller coils can have ultraviolet treated water, others not, and a comparison of microfouling (or heat transfer efficiency) made.

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II. INTRODUCTION

The concept of utilizing seawater to directly cool buildings was originally proposed for areas where cold seawater would be brought up from depth in the ocean.[1,2,3] It was felt that the biofouling problem would be minimal because:

1) Deep (below light extinction) offshore seawater has considerably fewer fouling organisms than shallow inshore waters;

2) Large diameter pipelines would be used, leaving room in the pipe for some macro-organism colonization before clogging becomes serious;

3) A plate type seawater/fresh water heat exchanger which could be readily cleaned would be used, and only treated fresh water would circulate through the chiller/fan coils.

The system proposed for the Corea Facility[4] differs from the original concept in two significant ways. The seawater is drawn from a depth of 50 feet in Prospect Harbor. This water is extremely fertile and abounds with potential fouling organisms and other particulate matter.

The seawater/fresh water heat exchanger is eliminated and seawater is circulated directly through special chiller/fan coils. This is done in the Corea design because the peak temperature of the bottom water in the Bay will be in the marginal range for moisture removal in the building, if an additional gain of 2-4°F due to the heat exchanger is added.

Reference is made to Figure 1 which illustrates the system schematically. The entire system is subject to macrofouling, or clogging by large organisms, which can enter the system in larval

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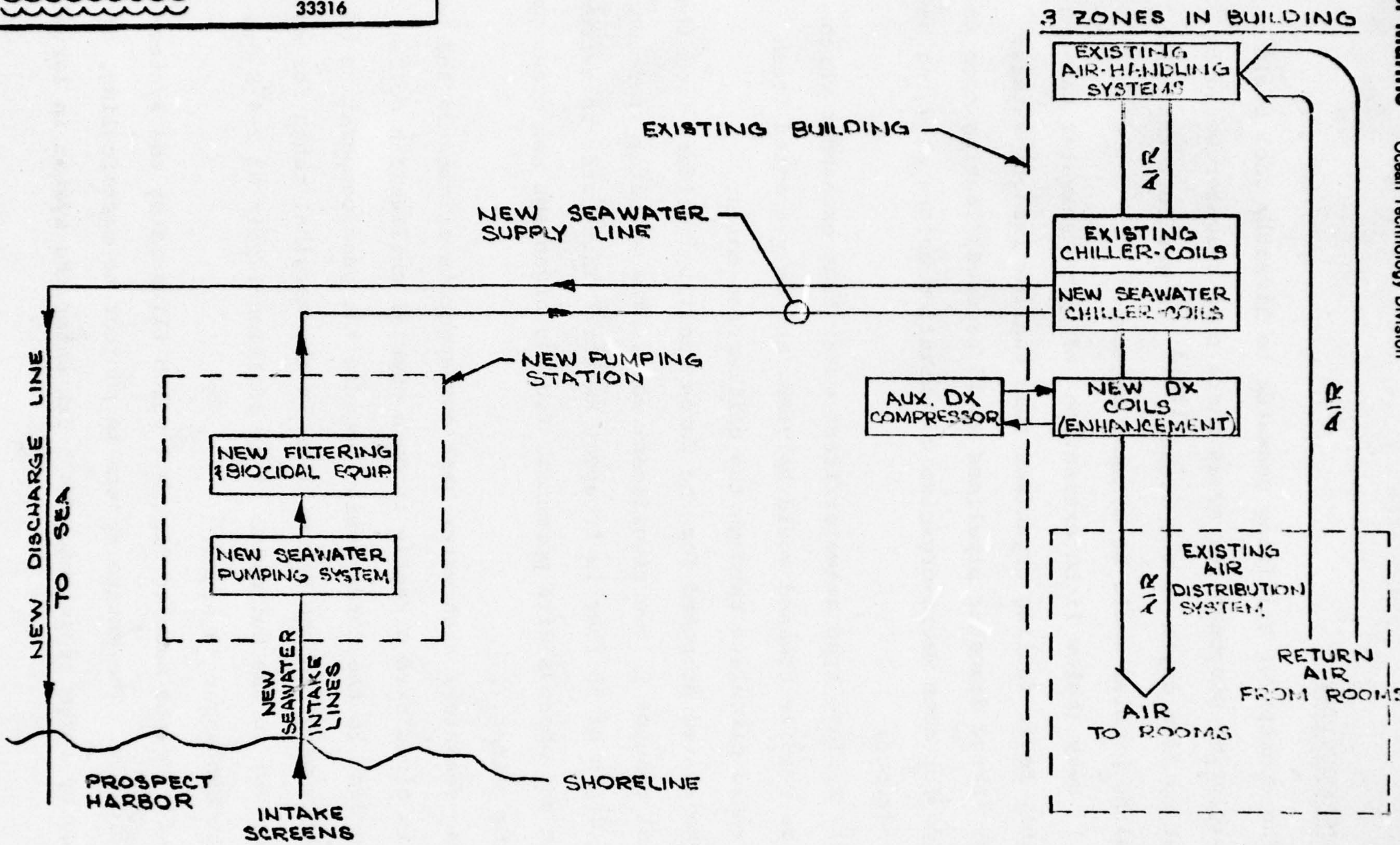

FIG. 1- SCHEMATIC OF PROPOSED SEAWATER AIR CONDITIONING SYSTEM (PER PRELIMINARY DESIGN, MARCH, 1977)

form (microscopic), attach, and grow in the system. This must be prevented in the design, or provision made for routine cleaning of the system.

The chiller coil unit is particularly vulnerable because:

1) It is made up of bundles of small diameter tubes which can clog easily, and

2) Even a thin layer of microfouling organisms will seriously reduce the heat transfer efficiency of these coils.

The preliminary design for the Corea Facility specifies filtering and non-chemical biocidal techniques (ultraviolet radiation) at the pump house. This will protect the land distribution parts of the system and the coils, but will leave the intake screens and intake pipeline vulnerable to fouling. Redundant intake pipelines have been specified to permit use of one line, while the other is being cleaned or treated to remove fouling.

The preliminary design specifies one satisfactory method of coping with the problem; however, it was felt that an additional study effort in the area of biofouling might result in a cheaper and/or more satisfactory design. The results of this additional effort are presented in this report.

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III. THE BIOFOULING COMMUNITY IN PROSPECT HARBOR

The purpose of this section is to 1) list the species of algae and animals that might present a fouling problem in Prospect Harbor and describe their natural history, 2) describe how the organisms will affect the system during their various stages, and 3) rank the organisms in order of predicted hazard to the cooling system, and 4) estimate the amount of suspended solids in the bottom water.

The information and data included with this report has been culled from the literature, questioning of other users of seawater, and personal observations of fouling communities in Penobscot Bay, Maine, and Prospect Harbor, Maine.

A. Species Assemblages. There are many species of algae and animals that will be encountered in Prospect Harbor (Table 1). Below is a general ecological description of individual taxa or groups of taxon.

1. Diatoms. Diatoms are microscopic unicellular algae with a size range of 5 µm to 1 mm. They lead both a planktonic and benthic mode of existence. The seasonal occurrence of diatoms in Prospect Harbor would exhibit a classical bimodal pattern with peak abundances appearing in late spring and early fall. Pelagic diatoms would simply pass through the system. If any did settle they would not survive long because of their light requirement for photosynthesis. Benthic diatoms require less light and are known to settle out and adhere to the walls of pipes. Benthic diatoms, together with bacteria, are the first colonizers of an epibiotic fouling

Table 1. List of plants and animals which may represent an epibiotic fouling community in Prospect Harbor, Maine.

PHYLUM: Protozoa	
SUBPHYLUM: Sarcomastigophora	
SUPERCLASS: Scarcodina	Foraminiferans
SUBPHYLUM: Cilliophora	
CLASS: Ciliata	Stalked Ciliates
PHYLUM: Porifera	
CLASS: Demospongiae	
Species:	*Haliclona* sp.
PHYLUM: Cnidaria	
CLASS: Hydrozoa	
Species:	*Campanularia flexuosa*
	Clytia johnstoni
	Gonothyrea gracilis
	Obelia dichotoma
	Tubularia larynx
	Tubularia tenella
SUBCLASS: Zoantharia	
Species:	*Metridium senile*
PHYLUM: Platyhelminthes	
Order: Polycladia	
Species:	*Euplana gracilis*
	Notoplana atomata
PHYLUM: Rotifera	Benthic Rotifers
PHYLUM: Nematoda	Nematodes
PHYLUM: Ectoprocta (Bryozoa)	
CLASS: Gymnolaemata	
Species:	*Electra pilosa*
	Electra monostachys
PHYLUM: Mollusca	
CLASS: Gastropoda	
Species:	*Dendronotus frondosus*
	Eubranchus pallidus
	Tergipes despectus
CLASS: Bivalvia	
Species:	*Anomia aculeata*
	Anomia simplex

Table 1. (cont.)

			Hiatella arctica
			Modiolus modiolus
			Mytilus edulis
PHYLUM: Annelida			
	CLASS: Polychaeta		
		Species:	Ampharetidae
			Harmothoe imbricata
			Glycera sp. (juvenile)
			Lepidonotus squamatus
			Nereis sp. (juvenile)
			Nereis zonata
			Potamilla neglecta
			Spionidae (juvenile)
			Spirorbis sp.
PHYLUM: Arthropoda			
	CLASS: Crustacea		
	SUBCLASS: Cirripedia		
		Species:	Balanus crenatus
			Balanus balanoides
PHYLUM: Chrysophycophyta (diatoms)			
		Species:	Biddulphia aurita
			Cocconeis sp.
			Fragillaria sp.
			Grammatophora sp.
			Licmophora sp.
			Melosira sp.
			Navicula sp.
			Nitzschia sp.
			Nitzschia seriata
			Pleurosigma sp.
			Rhabdonema sp.
			Thalassiothrix sp.
Macro algae			
	Ulotrichales		Ulva lactuca
			Enteromorpha spp.
	Laminariales		Laminaria sp.

community which will eventually lead to colonization by larger forms of fouling animals.

2. Macroalgae. Two species (Laminaria and Ulva) of macroalgae have been observed growing on the bottom in Prospect Harbor. These algae occur throughout the year and range in size from 15 cm to 2 m. They would not pass through the described cooling system if a screen with a large mesh aperature is placed in front of the intake pipe. However, there is the danger of the algae being torn from the bottom and covering the front of the intake pipe.

3. Foraminiferans. Forams are shelled amoeboid protozoans and range from 0.1 mm to 1 mm in size. These occur rarely during most any part of the year. They are pelagic and could settle out in the system, but they could easily be flushed out.

4. Ciliophora. This group of protozoans is represented by the tintinids in coastal waters. These animals are represented by both planktonic and sedantary species. They are approximately 20-500 μ in length and are found throughout the year, with the highest concentrations occurring during the summer. They do not represent a fouling problem. However, the sedentary species may attach themselves to the insides of the pipe and accumulate when not in use, thus contributing to the development of a climax community.

5. Demospongiae. Marine sponges are benthic animals and occur commonly in shallow waters. Their life cycle is represented by a pelagic amphiblastula larval stage (~50 μ) and sedentary adult stage. The larvae occur abundantly during late spring and summer.

Sponges have not been known to foul once through cooling systems.

6. Platyhelminthes. The body of these benthic animals are contactile, soft and usually flattened. After fertilization, eggs are laid to develop externally. Development is direct without special larval forms. Adult forms may appear in the cooling system during any time of the year. However, they do not attach themselves to any substrate and will be flushed through the system when in operation. They could be found at any depth in Prospect Harbor and range from 2-20 mm in size.

7. Rotifera. Benthic rotifers are smaller than 0.5 mm. They may be globular, or elongate and wormlike in morphology. Some are sessile while others are sedentary or pelagic. The larval stage is free swimming and direct development occurs. Rotifers may be found at any depth during any time of the year. In Prospect Harbor they may contribute to the initial colonization of newly exposed substrate. However, they are not a dominant fouling organism and are not expected to interfere with the proposed cooling system.

8. Nematoda. Nematodes are ubiquitous. They may range from the littoral to abyssal depths. They will be encountered in or on all substrate. Most species are less than 1 mm but some may reach 50 mm in length. Morphologically they are cylindrical worms without appendages. The young appear as juvenile worms, closely resembling the adult form. Nematodes will easily pass through the cooling system. However, once a fouling community has been established nematodes will be found within it.

9. Ectoprocta. Bryozoans are minute colonial animals forming encrusting, massive, stolonate or bushy colonies usually permanently fixed to a substratum. An individual animal of a colony is known as a zooid encased in a chitinous shell with or without an additional calcareous exoskeleton. The largest colonies of local species may be measured in hundreds of millimeters, while individual zooids are usually less than 0.5 mm long. The life cycle is represented by a free swimming cyphonante larval stage ($\sim$200-450 μ in length). Marine ectoprocts are entirely sessile. If the cooling system is constantly passing water, settlement of larvae probably will not occur. If the cooling system is not in use then colonization may occur. Their distribution is not depth or light dependent.

10. Annelida. Polychaetes are segmented annelid worms with appendages. There are both errant, sedentary and sessile species. Most of the species in Prospect Harbor are either errant or sedentary and can be found at any depth. They range from 2 mm-900 mm in size. The earliest larval stage is the trochophore, 0.2 mm-0.5 mm in size. The larvae are pelagic and occur throughout the year, reaching a peak during the spring and summer months. The larvae eventually sink to the bottom and gradually metamorphase into the adult form. The adult polychaete larvae will not colonize the intake pipes; however, if they do enter the system they may become clogged in the condenser tubes. One species, Spirorbis, forms sessile calcareous tubes. This polychaete could potentially contribute to the fouling of the intake pipe.

B. Dominant Species

1. Hydroids. Hydroids are considered to be important members of fouling communities because of their rapid growth and proliferation which lead to the formation of very dense colonies and thereby provide food and/or a suitable habitat for many other organisms. At least six species of hydroids are expected to appear in Prospect Harbor. They are: Tubularia larynx, T. tenella, Clytia johnstoni, Campanularia flexuosa, Obelia dichotoma and Conothyrea gracilis.

2. Tubularia spp: T. larynx and T. tenella are classed as boreal species, both with ranges extending from the Bay of Fundy to Cape Cod; there is also some southern extension of this range beyond the Cape. T. tenella is generally found from the littoral zone to a depth of approximately 71 m. T. larynx's range is somewhat more restricted, with colonies usually found from approximately 15-45 m.

Settlement of T. larynx is expected to occur from late summer through early fall, continuing until the water is cooled to less than 9°C. Colonies usually degenerate with further decreases in temperature.

Attachment of T. tenella is similar to that of T. larynx; however, it may begin settlement one or two months earlier than T. larynx.

3. Campanularidae: Settlement of Clytia johnstoni may occur at most any time of the year. However, maximum settlement probably occurs during late summer and fall. Settlement of Campanularia flexuosa occurs during summer and autumn. The dominant species during spring and early summer is Obelia dichotoma. This species covered the moorings and instrument packages during the July change

out in Prospect Harbor and probably is the most common form found in the harbor. The abundances of hydroids may be affected by the predation of nudibranchs and by the settlement of larval bivalves which are known to attach to hydroid stalks in such numbers that individual members of the colony die from either competition for food or overcrowding.

The life cycle of the above hydroids is represented by both pelagic medusoid and sessile polypoid stages. The medusoid stage ranges from 2 mm to 40 mm in size and the colonial polypoid stage 5 mm to 200 mm. The larval development is represented by a free swimming planula or octinula stage (length ca. 0.5-1.0 mm).

4. Mollusks.

Bivalves: *Anomia simplex* settlement in Maine waters usually begins in July and ends by the middle of October with the heaviest time of settlement occurring in August. *A. simplex* has a life span of approximately two years and reaches 30 mm in size. *Anomia aculeata* also occurs in large numbers and periods of attachment are similar to *A. simplex*.

Spat of the bivalve *Hiatella arctica* are usually dominant during the summer and late summer. Settlement of *Mytilus* is temperature dependent and does not occur until temperatures reach between 10° and $14^{\circ}C$. When the temperature drops below $12^{\circ}C$, settlement usually stops. Veligers of *Mytilus* are substrate selective, preferring a filamentous substrate, macroalgae or hydroids. Adults are usually 75 mm in size.

The settlement of the horse mussel, *Modiolus modiolus*, is similar to that of *Mytilus edulis* and reaches a length of 155 mm. The horse

mussel was observed in the area of the proposed intake. The horse and blue mussel should be of primary concern because they represent a climax fouling community. The larval veliger stage is pelagic and approximately 50-100 µ in length. Once settlement has occurred the veliger stage metamorphases into the adult form (initial size, 0.5-1.0 mm).

5. Nudibranchs: Several species of nudibranchs may be encountered in Prospect Harbor, especially on colonial hydroid beds. They may be found throughout the year but most abundant during the warmer months. These animals are sedentary but not sessile. They range from 1-90 mm in size. The larval stage is approximately 100 µ. Adults are found at most any depth.

6. Barnacles.

Balanus larvae settlement begins in April and continues through June and usually decreases in July and August. However, observations in Prospect Harbor show heavy settlement during August. For any given year the attachment of larvae will vary depending upon temperature or some other environmental stimulant. The larval nauplier stage of the barnacle is approximately 100 µ in length. Once settlement has occurred, the larvae metamorphases into the adult, attaining a basal diameter of 25 mm.

C. General Discussion

Investigations of settlement upon panels suspended from rafts have been informative with respect to the mode of development of fouling communities. Such communities undergo a succession of

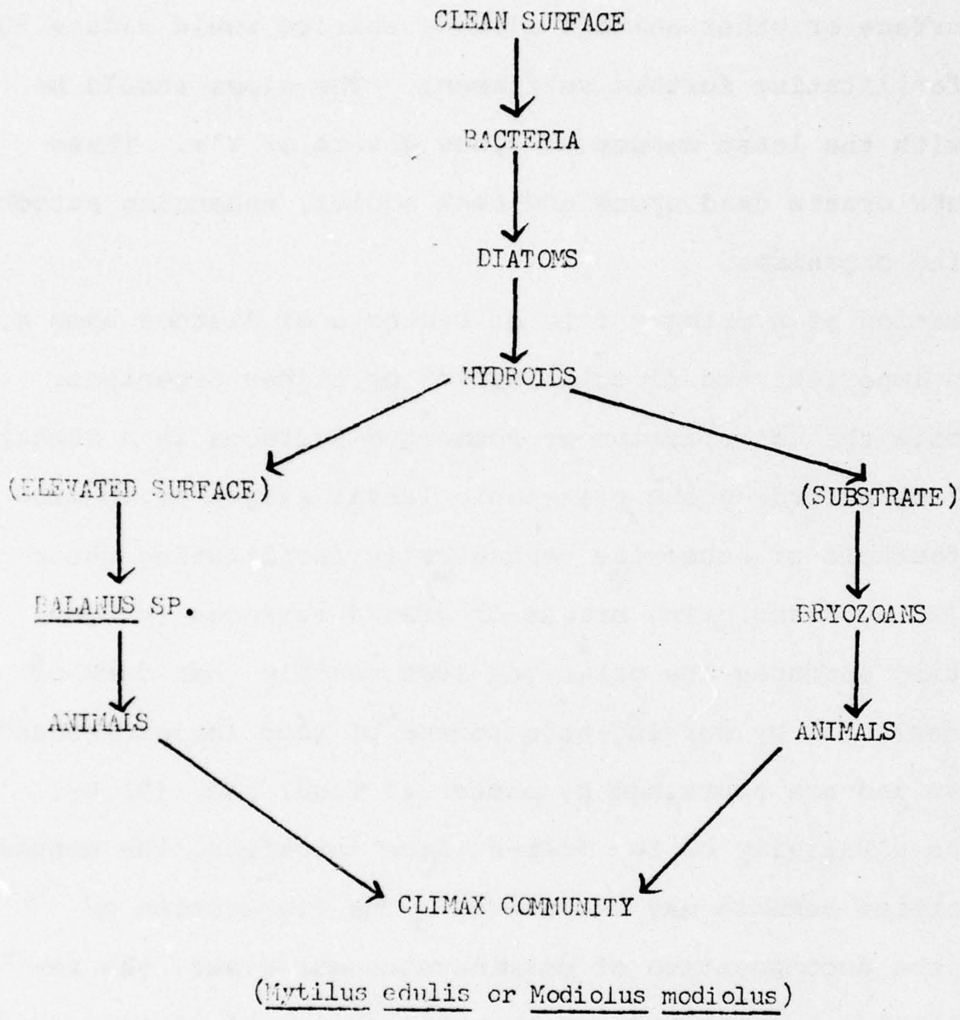
change from the original clear surface to a climax community of Mytilus (Figure 2). It has been shown that individual species of fouling organisms have a characteristic period in which settlement takes place consequent upon the seasonal rhythm of reproduction. It must be remembered that abiotic and biotic environmental factors decisively affect the growth of settling marine plants and animals. Variations in temperature and salinity as well as in the abundance of planktonic organisms, competitors and predators will cause shifting in the annual beginning of settlement and in the abundance of settled organisms.

Upon prolonged immersion of man-made materials the composition of the fouling population changes. Barnacles and hydroids which succeeded the primary microbiological slime do not survive but are replaced successively by bryozoans, ascidians and Mytilus.

It should also be considered that water velocities have a considerable bearing upon the manner and quality of settlement. Speeds above 2 knots are sufficient to prevent settlement of sedentary and sessile animals. However, speeds above 5 knots must be maintained to prevent attachment of Mytilus edulis.

When larvae enter a water intake structure, the flow velocity in the body of water decreases as the walls are approached and as the drag of this solid boundry brings to rest the water in immediate contact with it. The velocity gradient across the larva imposes upon it a spinning force which increases with proximity to the boundry and attachment becomes difficult. However, the fluid shears near the walls of the conduit; thus, the spinning movement of the larvae decreases through the entry length, but remains constant thereafter.

Figure 2. Successional sequences that may be expected in Prospect Harbor, Maine.



Therefore, the chance of settlement increases along the length of the intake pipe and would be demonstrated by an increase in fouling which occurs with distance from the mouth of the pipe. Any roughening of the surface or other animals already settled would reduce the shear, thus facilitating further settlement. The pipes should be constructed with the least amount of elbow joints or T's. These types of joints create dead spots and back eddies, enhancing attachment of fouling organisms.

The formation of a primary film of bacteria or diatoms upon a surface is an important aid to colonization by higher organisms. Bacteria promote the colonization of submerged surfaces in a number of ways: (1) by affording the planktonic larval stages of fouling organisms a foothold or otherwise mechanically facilitating their attachment; (2) by discoloring bright or glazed surfaces (bright, light-reflecting surfaces are colonized less readily than dark or discolored ones); (3) by serving as a source of food (barnacles and mussels ingest and are nourished by bacterial food) and; (4) by increasing the alkalinity of the film-surface interface, the deposition of calcareous cements may be favored. The elaboration of ammonia from the decomposition of poteinaceous materials, the reduction of nitrates or nitrites, or the utilization of organic acids are bacterial processes which intend to increase the alkalinity; (5) by influencing the potential of the surface upon which they are growing, bacteria might expedite the attraction and attachment of fouling organisms; (6) by increasing the concentration of plant nutrients at the expense of the accumulating organic matter, bacterial activity tends to favor the growth of algae; and (7) where a toxic

surface is present (i.e., antifouling paint) the bacterial film may have a protective function for barnacles. It has been shown that the particulate and dissolved organic matter which accumulates on solid surfaces both precedes and explains the development of bacterial films upon them. Many bacteria of a sessile or periphytic habit prefer to grow only on solid surfaces.

Although bacteria are important in primary film formation, diatoms are considered to be preeminant because: (1) apart from the bacteria they are the most numerous representative of the microflora able to fulfill this function; (2) they are present at all seasons of the year; (3) they produce oxygen and provide a rich source of nutriment for the bacteria; (4) they affect the hydrogen in concentration of the slime; and (5) they are highly resistant to copper and mercury which are used widely in antifouling paints.

Tubularia larynx is a source of trouble at some power plants using once through cooling systems. It reproduces by means of an actinula larva which is discharged by movements of the gonophore. Once liberated, it is apparently unable to swim and has little ability in selecting a site for settlement. At settlement, the larva becomes attached to a surface by the discharge of menatocysts on tentacles which point toward the aboral pole; settlement is considered to be complete when the larvae are attached by the aboral pole and the tentacles are free. Temperature has little effect upon the settlement of the larvae, but a greater settlement occurs either in total darkness or in alternating dark and light than under continuous illumination. Because the initial attachment can occur only when the tentacle tips touch an object, the actinula can settle suc-

cessfully only when the nematocyst threads can withstand the strains imposed by a water current, but once such attachment has occurred, it will remain permanent irrespective of whether the locality is ultimately suitable for growth or not. Such behavior explains the gregariousness of _T. larynx_.

Once permanent attachment has occurred growth is rapid. However, colonies are known to become moribund during the summer with regeneration occurring in the fall. The sequence of activity and dormancy of the colonies is apparently under the control of endogenous, rather than exogenous, factors. Once settlement of _T. larynx_ is established other organisms soon become associated with it or prey upon it.

The serpulid polychaetes secrete calcareous tubes by which they attach themselves to the substrata. The spirorbid _Spirorbis_ sp. is characteristically an inhabitant of fucoid algae upon which it may occur in large numbers. Its larvae are liberated mainly about the time of the moon's quadrature. Upon liberation, these larvae are positively phototactic for up to two hours after which they swim at random; for another two hours they visit a large number of different surfaces, crawling upon them and swimming off again. Once a suitable surface is chosen they secrete an initial semi-transparent tube and metamorphase. These larvae will settle upon a glass or stone surface only if it is colonized already by a bacterial film, but they have a strong preference for _Fucus_, a marine macroalgae. Concentrations of recently settled individuals can reach 10-20/cm^2. After swimming for eight hours the rate of settling declines and many larvae are apparently too weak to settle successfully.

The barnacles are of great interest because the mechanism of their settlement has been so widely studied. The adult of the barnacle releases nauplius larvae at a time of year which is characteristic of the individual species. The larva spends a prolonged life in the plankton at the end of which, in the period before settlement, it becomes a cyprid larva (0.5-1.0 mm) which seeks a suitable surface for attachment, settles and undergoes a metamorphosis to the adult form.

The currents of their environment transport the nauplius and cyprid larvae in a manner consistent with their form and behavior; and in areas in which the current is too strong, the cyprid is unable to settle. During settlement a cyprid responds to surface texture and to surface contour. The cyprid larvae tend to settle in grooves and is described as rugophilic tendency; the cyprids can orientate along grooves which are either much smaller or considerably larger than themselves. Settlement of the cyprid stage is always greater when it occurs in the presence of barnacles which have previously colonized some type of substrata. Cyprids may also respond positively to the bases of dead barnacles, but an abundance of older barnacles may make some cyprids leave a surface without metamorphosing. Like most other benthic animals the amount of settling by barnacle larvae is highly variable from year to year. These variations may be the result of abnormalities in the abundance of food, lowered viability of larval input, increased predation, etc.

The bryozoans which represent a stage of colonization intermediate between the balanoid, algal and hydroid communities and the climax community settle most readily at the lowest water speeds.

Climax populations are composed largely of mussels. The most common is _Mytilus edulis_. This species has a free swimming planktonic larva, a stage which has a duration of about four weeks. Settlement can occur at any time after the formation of the veliger stage from 0.4 to 1.0 mm and is heaviest on floating structures in the region between the water line and a depth of two feet. On the beach, intertidal structures and seabeds in estuarine areas, there is little persistent settlement above the mean tidal level and the heaviest settlements take place at and below the mean low tide. _M. edulis_ is not expected to be much of a nuisance in Prospect Harbor because of this distribution. However, the horse mussel, _Modiolus modiolus_, may be a problem because of its deeper distribution.

D. Ranking of Organisms

The dominant members of a fouling community expected to appear in Prospect Harbor are hydroids, mollusks and barnacles.

1. _Hydroids_. Hydroids are considered to be important members of fouling communities because of their rapid growth and proliferation which lead to the formation of very dense colonies and thereby provide food and/or a suitable environment for many other organisms. Their life cycle is represented by both pelagic medusoid and sessile polypoid stages. The medusoid stage ranges from 1 mm to 40 mm in size, while the colonial polypoid stage ranges from 5 mm to 200 mm in size. They may be found at any depth in the water column and settlement is usually not dependent upon light.

2. Mollusks. This group of animals is most likely to be represented by blue and horse mussels in Prospect Harbor. The larval veliger stage is pelagic and approximately 50-100 μ in length. Once settlement has occurred, the veliger stage metamorphoses into the adult form (1-100 mm). The blue mussel usually spawns twice a year, once in the spring and again in late summer.

3. Barnacles. The life cycle is represented by a pelagic nauplier stage ($\sim$50-100 μ) and a sessile adult stage ($\sim$1-20 mm). Barnacle larvae are found throughout the water column and settlement is not dependent upon light.

E. Suspended Solids

The maximum value of suspended solids obtained from bottom water in Penobscot Bay is 50 ppm. It is suggested that a value of 100 ppm be used as the value for filter design in the absence of actual data from Prospect Harbor. Such data should be taken during the vernal run-off.

IV. BIOFOULING COUNTERMEASURES

A. General

Conventional measures to prevent biofouling in seawater systems consist of variations of the following techniques:

1. Toxic material or coating
2. Chemical treatment of the water (chlorine, ozone)
3. Velocity control of the water
4. Temperature control of the water.

These techniques are rarely completely effective, and some method of periodic cleaning is generally used in conjunction with them, such as:

1. Manual scrapers, brushes, etc.
2. Automatic brushes, balls, pigs, etc.
3. Water jet systems
4. Chemical cleaning.

Some modern techniques under development and in use in small seawater systems are:

1. Ultrasonic fouling prevention and cleaning
2. Ultraviolet irradiation
3. Monomolecular coatings.

Operators of seawater aquaria have adapted some of the mechanical filtering techniques used in drinking water supply and swimming pool systems to remove larger organisms and larvae, and non-chemical germicidal techniques, such as ultraviolet radiation, to kill microscopic organisms.

The most satisfactory of these use natural sand deposits as filters. The New York Zoological Society at Coney Island, New York, draws seawater from the offshore sands of outer New York Bay. The Union of the Pacific College in California draws seawater from a well dug in a sand beach at low tide. The first is an adaptation of the slow sand filter used in the water treatment industry. Instead of regularly removing and cleaning the top half-inch or inch of the bed as in a normal slow sand filter, natural wave action prevents the sand from clogging in the installations cited above. The second is simply a seawater well.

There is a large and rapidly growing literature on the subject of marine biofouling. This literature was reviewed and those articles found useful in the course of our work are cited in the Bibliography. A number of manufacturers of biofouling prevention and cleaning equipment were contacted and a representative listing of these is given in Appendix A. Manufacturers' catalogs and specification sheets received are on file.

B. Specific

1. Requirements

The system requirements and the biofouling problem at the Corea facility are similar in many respects to those experienced in seawater aquaria in that 1) a relatively long, small diameter intake pipe must be kept free of macrofouling organisms to prevent clogging, and 2) additionally, in the design option that eliminates the seawater/fresh water heat exchanger, it might be desirable to eliminate bacteria and other microorganisms. Not to prevent disease,

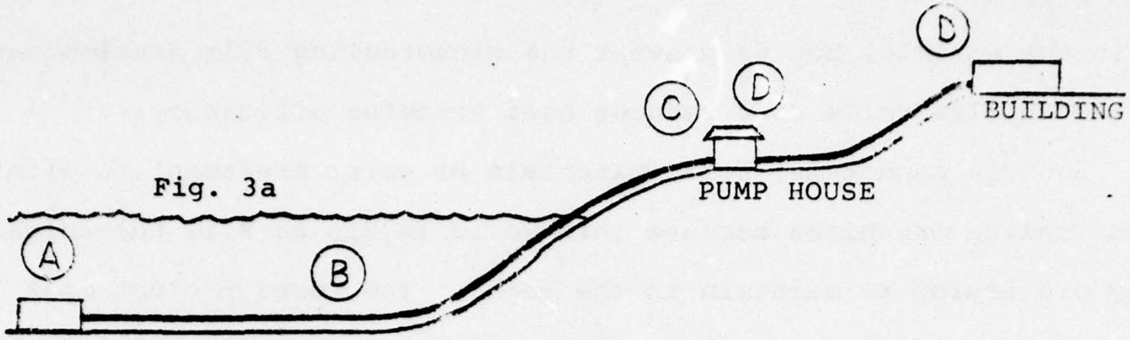
as in the aquaria, but to prevent the microfouling film development in the chiller coils that reduces heat transfer efficiency.

Aquaria cannot use toxic materials or water treatment to eliminate fouling organisms because this would injure or kill the animals they are trying to maintain in the tanks. The Corea project does not have this fundamental restriction; however, because the discharge area is heavily fished for lobster, every effort will be made in the design to eliminate or minimize the use of toxic chemicals.

2. a) The Preliminary Design - One of the design criteria used in the preliminary design was that the seawater cooling system was to be operational at all times (no shutdowns). To meet this criteria, duplicate seawater pipelines were specified to permit maintenance on part of the system while the rest of the system remained in operation (Figure 3a). Mechanical filters (rapid sand filters) were located on the positive side of the pumps. These filters are designed to remove larvae and other particulate matter larger than 15 microns. Ultraviolet treatment of the water after filtering is specified to kill bacteria and other organisms below 15 microns in size to prevent microfouling in the chiller coils.

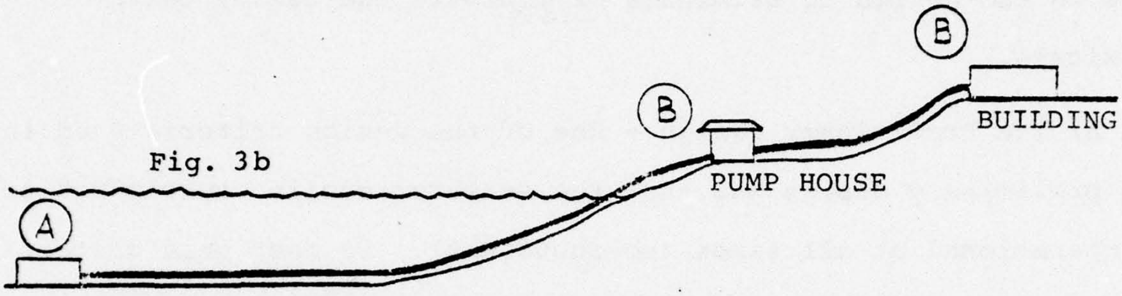
The offshore intake pipeline in the above configuration has a coarse screen to keep large animals and material out of the pipe; however, it is exposed to the larvae. The larvae will deposit and grow in the intake pipe and measures must be taken to routinely prevent this growth from accumulating to the point where flow is inhibited in the pipeline. Because duplicate intake pipelines were

Fig. 3a



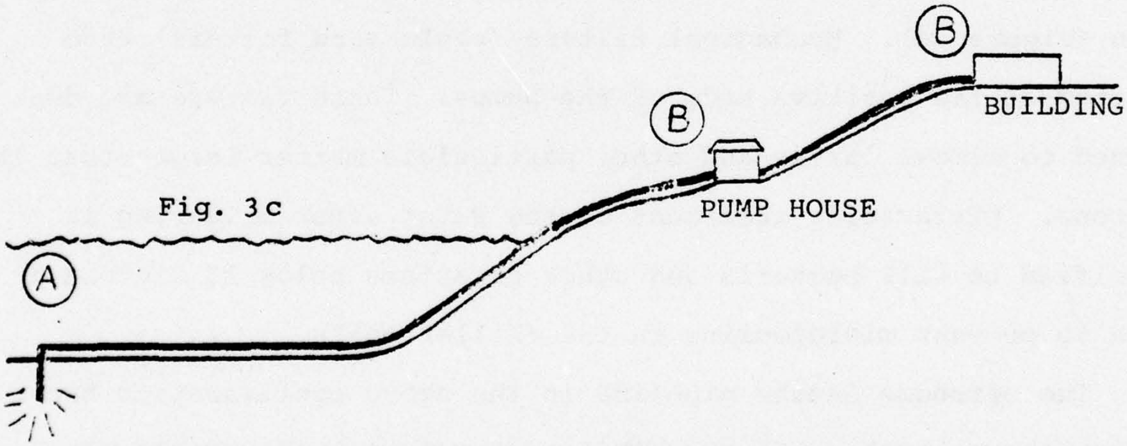
A. Intake screen.
B. Redundant pipelines.
C. Fast sand filter or other mechanical filter at pump house.
D. UV or other biocidal at pump house or building.

Fig. 3b



A. Man-made fast or slow sand filter, at intake.
B. UV or other biocidal, at pump house or building.

Fig. 3c



A. Man-made seawater well or natural slow sand filter at intake.
B. UV or other biocidal at pump house or building.

FIGURE 3. BIOFOULING PREVENTION CONFIGURATIONS CONSIDERED

specified, intakes can be alternated every two weeks or so. Experience at an aquarium in Boothbay Harbor indicates that the dormant line turns anaerobic, killing the young organisms that have accumulated. Variations of this technique are to fill the intake pipeline with fresh water or even chlorinated water during its dormant period. Provisions are made as well for Y's and other openings in the line to permit mechanical cleaning of the line with brushes, water jets or "pigs" if required.

b) Slow Sand Filters and Rapid Sand Filters - It was decided after the preliminary design was completed that the existing air-conditioning system would be used as a back-up during maintenance of the seawater system. With duplicate pipelines no longer a system requirement, other means were sought to keep the intake free from fouling; namely by preventing the larvae from entering any part of the system, including the intake pipeline. Systems of the type illustrated in Figures 3b and 3c were evaluated. These would utilize either natural sand beds (if available) or man-made filters at the intake to eliminate particulate matter over 15 microns in size.

Since earlier diver reconnaissance did not reveal suitable sand beds for a natural filter, the use of man-made filters was examined. A slow sand filter is a possibility, with natural wave action providing the cleaning of the surface. It was calculated that a minimum sized filter roughly 50 feet x 50 feet x 3 feet would be required (Appendix B-1). This is a sizable structure and would be costly. An old sand/gravel barge or similar structure could be converted to such a filter, floated to the site and sunk on location.

The use of a rapid sand filter at the intake location was also examined (Appendix B-2). One or more relatively small and inexpensive filters could be provided; however, rapid sand filters require frequent backwashing. The backwash flow required is five to nine times the basic flow; 2600 gpm or 13,000 gallons for a five-minute wash would be required for our system. This could be provided by pumps (2600 gpm pump) or by a storage reservoir up the hill filled with waste water. Both these solutions are costly and the second impractical because of the freeze-up problem. Furthermore, the backwash flow is so much greater than the normal flow that a large backwash pipe (14 inch diameter) would be required. If the original intake pipeline was built oversized for use as a backwash pipe, a system of underwater valving at the intake would be required, and these would have to be manipulated every ten hours during the peak period of particulate matter in the Bay.

c) The possibility of utilizing a seawater well exists if the Bay sediments in the intake area are suitable for this application. The technique has been used in desalinization plants and seawater aquaria. This is illustrated in Figure 3c and discussed in the next section.

3. Seawater Well

It seems obvious that the best solution for the Corea site would be to try to utilize any natural sand beds that might exist in the deeper part of the Bay as an intake filter. While the charts and spot dives did not reveal sand, the offshore survey[5] conducted for pipeline routing took a number of sediment cores in the intake

area to determine the anchoring and bearing properties of the sediment. No clean sand beds were found.

Logs of the sediment borings and their locations are shown on the charts in Appendix C. In the proposed intake area, four to fifteen feet of sediment is found overlying the granite rock of the area. One boring, B23, was stopped after 15 feet when no rock was reached. The sediments as described by the driller are silty sands with shells (approximately four feet) usually overlying a silty clay. Samples were taken and retained.

While this material is not ideal for use as a natural filter, there is an excellent possibility that it has sufficient permeability to husband a seawater well. One or more well points adequate for the roughly 300 gpm flow required would be installed in the most suitable layer of sediment. Clean sands and gravel can be inserted around the well point (packing) to prevent local clogging and to enhance flow into the well point. Seawater will flow horizontally into the well zone rather than vertically as in a slow sand filter. The vertical movement of the seawater into the layer tapped will be over a very large area of the Bay bottom.

In order for the well to be successful, the sediments must be permeable enough to permit the design flow. Head losses must also be kept low because the intake system proposed is a system with the pumps on shore. Analysis of the samples already taken would provide a good indication of whether this technique could be used in this location. If the sediment analysis indicates good possibilities, a test well can be readily sunk to provide complete design data.

Utilizing a seawater well of the type described has many benefits: (a) Larvae and other particulate material will be removed; (b) Bacteria populations will be greatly reduced, possibly to the point where further treatment with ultraviolet equipment is unnecessary; (c) The transient temperature peaks observed in the bottom water[6] will be smoothed. Ground water on land maintains a fairly constant temperature that is roughly the annual average of the local air temperature. The sediments of the Bay will certainly act to "filter" out the short-term temperature rises observed during downwellings and will probably provide lower temperature seawater during the warmest months than an intake located on the bottom would; (d) The initial cost of a well would be less than other systems considered; (e) The operation and maintenance costs would be minimal; (f) The intake would have no influence on the life in the Bay as would an intake on the bottom.

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Communication with Mr. Jim Worthington, University of the Pacific, Pacific Marine Station, Dillion Beach, California 94929.

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APPENDIX A

MANUFACTURERS OF EQUIPMENT

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CHLORINATION

Capital Controls Company*
Advance Chlorination Equipment
Post Office Box 211
201 Advance Lane
Colmar, Pennsylvania 18915
Contact: Mr. Shulzer

Fisher & Porter Inc.
Warminster, Pennsylvania
Contact: Mr. Robert Edwards

*Literature on file

FILTERS

AMF Cuno Division*
402 Research Parkway
Meriden, Connecticut 06450
Contact: Mr. Don Onnen

Buffalo Filters Division
Bos-Hatten Inc.
French TR and Old Union
Buffalo, New York 14224

The Delaval Separator Company*
Poughkeepsie, New York 12602
Contact: Mr. D. M. Landis, Chemical Processes Sales

Diaclear Inc.*
1070 Sherman Avenue
Hamden, Connecticut 06514
Contact: Mr. Terrill Vidal, Sales Engineer

Duriron Company, Inc.*
9542 Hardpan Road
Angola, New York 14006
Contact: Mr. John Godso, Manager

Electro Refractories & Abrasives*
Division of Ferro Corporation
9 McDonald Park
East Rochester, New York 14445
Contact: Mr. Veeder

Filtrex Incorporated
Post Office Box 485T
Lincoln Park, New Jersey
Contact: Mr. Vince Pisanni, Sales

Hydromation Filter Company*
39201 Amrhein Road
Livonia, Michigan 48150
Contact: Mr. Jack R. Bratten, General Sales Manager

*Literature on file

FILTERS (cont.)

Polyclon, Inc.*
15 Sixth Road
Woburn, Massachusetts 01801
Contact: Mr. James W. Lupien, Vice President

Purex Industrial Equipment*
18400 East Mohr Avenue
City of Industry, California 91747
Contact: Mr. Gordon Inman, Sales Engineer

R. P. Adams Company, Inc.*
225 East Park Drive
Post Office Box 963
Buffalo, New York 14240
Contact: Mr. B. R. Wixson, Assistant Sales Manager

Roberts Filter Mfg. Co.
Darby, Pennsylvania 19023
Contact: Mr. George Matsinger

Velcon Filters Inc.
1750 Rodgers Avenue
San Jose, California 95112
Contact: Mr. Martin, Sales

Xodar Corporation*
Powder Hill Drive
Lincoln, Rhode Island 02865
Contact: Mr. David P. Gagnon, Sales Manager

*Literature on file

ULTRAVIOLET IRRADIATION

Aquafine Corporation*
New Preston, Connecticut 06777
Contact: Mr. Craig A. Reynolds, Eastern Regional Manager

Atlantic Ultraviolet Corporation*
250 North Fehr Way
Bayshore, New York 11706
Contact: Hilary Boehme

Refco Purification Systems Inc.*
Post Office Box 2356
2010 Farallon Drive
San Leandro, California 94577
Contact: Mr. Robert E. Flatlow, Vice President and Gen. Manager

Ultra Dynamics Corporation*
1631 10th Street
Santa Monica, California 90404
Contact: Mr. G. S. Domino, P.E., Sales Engineer

Xodar Corporation*
Powder Hill Drive
Lincoln, Rhode Island 02865
Contact: Mr. David P. Gagnon, Sales Manager

*Literature on file

APPENDIX B

SLOW AND RAPID SAND FILTERS

APPENDIX B - SLOW AND RAPID SAND FILTERS

1. Slow Sand Filter

The slow sand filter, or gravity sand filter, operates at filtration rates of from 2.5 to 6 million gallons per acre per day (approximately .04 to .10 gallon per min per square foot). This type of filter is capable of removing fine particulate matter and even bacteria from the water. Bacterial counts are reduced by 99 percent in this type of system. The characteristics of slow sand filters include sand depths of 30 to 36 inches, under drain facilities, cleaning frequencies of 2 to 11 times per year, and a requirement of at least two units to permit alternate cleaning. The technique used to clean these slow sand filters is to physically remove the surface layer, top few inches, of dirty sand and periodically clean or replenish the removed sand when the filter depth approaches 20 to 24 inches.[7,8]

The filter area required for <u>one</u> filter of this type at a filtration rate of 280 gallons per minute would be between 2,800 square feet and 7,000 square feet. In the underwater application under consideration, wave action will agitate the upper layer of sand and currents will remove the collected organic material. The cost of constructing a slow sand filter of the size required would be very high; however, two variations of the basic design should be examined for this site:

a) The natural sediments in the intake area should be examined to determine if natural sands at the site could be used as a slow sand filter.

b) The use of an old sand/gravel barge or similar structure, if available cheaply enough, could be converted to a slow sand filter, towed to the site, and sunk on location.

2. Rapid Sand Filter

a) General

The rapid sand filter is the conventional down flow sand filter, in which the flow of dirty water enters the fine beds of the filter at the top and flows downward. The particulate matter is captured in the fine media at the very top of the filter bed. The relatively small pore space between these fine sand grains at the top of the bed results in a limited solid-holding capability, since the solids only penetrate 7 to 12 inches into the bed. The rapid sand filter can be operated at a filtration rate of from two to three gpm per square foot and has a solids-holding capacity in the range of one pound per square foot of surface area.[9] This type of filter is capable of filtering particulate matter of the 12 micron size and larger, as indicated by Mr. Beeban of the Miami Seaquarium.

The surface area of the sand filter(s) bed that would be required, using a filtration rate of two gallons per minute, is 140 square feet. It was thought originally that this 140 square feet of surface area could be distributed among multiple, separate filter beds at the offshore intake location, which would then allow the total combined pumps discharge to be manifolded to one filter for the duration of the backwash cycle. This is a standard approach to the different flow rate characteristics between the filtration and backwash cycles. This is necessary because of the higher required

backwash rate of five to nine times the filtration rate, approximately 10 gpm per square foot to 18 gpm per square foot, or about 100 times the slow sand filter. However, this would not be practical at the offshore intake for three reasons: multiple suction and discharge pipe runs required to the manifold located at the pump station, problems encountered trying to balance the filtration flow rate through the individual filter beds, and the different pump characteristics required because of the vast difference between the filtration flow rate and the backwash flow rate. This does not preclude the use of a multiple filter system at the pumphouse location.

The sand layer in rapid sand filters is commonly 24-30 inches deep. The effective size of sand (sometimes called the 10 percent size, being that size such that 10 percent of the sand grains by weight are finer than it) ranges from 0.35 to .60 mm, depending upon the purpose of filtration. The maximum uniformity coefficient (defined as the 60 percent size divided by the 10 percent size) is usually specified between 1.6 and 1.7. Sand with a higher uniformity coefficient (above 1.7) is separated into coarse and fine strata by backwashing, which reduces filtering efficiency and makes the sand more difficult to keep in good order. Voids in filter sand range from 35 to 45 percent according to the uniformity of the sand, the shape of the particles, and the method of packing. Close packing is obtained with sand either perfectly dry or saturated with water.[7]

In most filters the sand is supported on several layers of graded gravel, with the finest layer immediately below the sand and the coarsest material at the bottom of the filter packed around the

underdrain system. The underdrain system serves the double purpose of carrying off the filtered water and distributing the wash water in the reverse direction. The fundamental requirement of any underdrain system when used for washing is that it shall give an equal dispersion of fresh water over the whole area of the filter. The porous plate underdrain, vitrified or fused crystalline aluminum, is designed to provide an even upward velocity over the entire filter bottom. These plates are placed either to provide a false bottom or on top of the concrete channels. The head loss through the porous plate type underdrain at a wash rate of 30 inches per minute is 1.3 feet, which represents the lowest head loss of any underdrain type (Wheel bottoms, 6.5 feet and Leopoid blocks, 1.5 feet).[7] While communicating with Mr. Veeder of Filtros (Electro Refractories & Abrasives/Division of Ferro Corporation, 9 McDonald Park, East Rochester, New York), a manufacturer of fused aluminum oxide porous ceramic underdrain plates, it was indicated that the head loss through this underdrain plate at a filter rate of 2 to 4 gallons per minute per square foot would be negligible, the significant head loss associated with the filtration rate in the filter is due to the head loss through the sand, and that the backwash flow rate head loss figure of 1.3 foot would be a valid figure to use.

Loss of head is the frictional resistance of the sand to the passage of water. It is affected by sand size, degree of uniformity of sand size, particle shape, cleanliness of the sand, degree of air binding, and temperature. For any given condition of the filter bed the loss of head is directly proportional to the rate of filtration. The loss of head in a filter is made up of two parts:

the frictional resistance of the sand itself, and the resistance due to the accumulation of dirt on the surface of the filter.[7]

b) Specific

The following computations were made for two rapid sand filters at the intake location; each capable of handling the entire 280 gpm flow.

(1) Filtration Head Loss Calculation

The sand in a rapid sand filter is considerably stratified according to size; the finest material at the top, relatively uniform, of greater porosity, and the head loss is less than through a mixture of coarse and fine sand. Experiments by Hulbert and Feben at Detroit resulted in the following formula:[7]

$$\ell = \frac{27}{10^5} \left[\frac{dr(73 - p)}{s^{1.89}(t + 20.6)} \right]$$

where ℓ = loss of head in feet.

d = depth of sand in inches.

r = rate of flow, mgd per acre (million gallons per day per acre).

p = porosity (% voids by Jackson Turbidimeter method).

s = sand size in mm (50% or median sieve size).

t = water temperature, degrees F.

In applying the Detroit formula to a filter bed, the bed is assumed to be composed of several shallow layers, with the finest material at the top and coarsest at the bottom.

The median sand size for each layer is determined from the sieve analysis, and the head loss is calculated for each layer, ℓ_1, ℓ_2, ℓ_3, etc. The total head loss $L = \ell_1 + \ell_2 + \ell_3$, etc.

In figuring the frictional head loss in the proposed rapid sand filter, the following assumptions are made:

d = 30 inches, the sand is of one homogeneous type, i.e., it has a low uniformity coefficient with an effective size of .40 mm.

r_1= 125.5 mgd per acre ≈2 gpm per square foot.

r_2= 251 mgd per acre ≈4 gpm per square foot.

p = 35 percent, this assumption is conservative.

t = 50°F.

$$\ell_1 = \frac{27}{10^5}\left[\frac{(30)(125.5)(73 - 35)}{(.48)^{1.89}\ (50 + 20.6)}\right]$$

$$= \frac{27}{10^5}\left[\frac{1.4307 \times 10^5}{17.634}\right] = 2.19 \text{ ft.}$$

$$\ell_2 = \frac{27}{10^5}\left[\frac{(30)(251)(73 - 35)}{(.48)^{1.89}\ (50 + 20.6)}\right]$$

$$= \frac{27}{10^5}\left[\frac{2.8614 \times 10^5}{17.634}\right] = 4.38 \text{ ft.}$$

(2) Filter Backwash Requirement Calculations

As a general rule, the rate of filter washing that will lift or expand the filter sand by 50 percent is sufficient to keep the sand clean and on the other hand will not wash out too many of the fine particles and change the character of the filter. The wash rate required depends upon the grain size and shape of the sand and upon the temperature of the water.[7]

The Hazen formula for sand expansion is

$$R = 30d^{1.5}(1 + 0.06\%\ \text{expansion})\frac{t + 30}{80}$$

where R = rate of rise inches per minute.

d = effective size in mm.

t = temperature (Fahrenheit).

Assume sandsize = .48 mm (median) and effective size = .40 mm.

$t = 50^{O}F$.

$$R = 30(.40)^{1.5}(1 + 0.06(50))\ \frac{50 + 30}{80}$$

$$= 30.357 \text{ inch per minute}/{\approx}30 \text{ inch per minute.}$$

Washing of a filter takes between five and ten minutes. A 125.5 mgd filter bed with a sand area of 145 square feet will require 2,618 gpm for a wash at 30 inches rise per minute, or 13,090 gallons for a five minute wash. Using a direct pumping backwash system, the pump would need a capacity of not less than 2,600 gpm. The proposed max capacity of the three-140 gpm pumps in parallel equals 420 gpm. Therefore, the number of filter beds required would equal 2,618 gpm/420 gpm = 6.23 or seven beds, each of 140 sq. ft./ 7 beds = 20 sq. ft. This is impractical at the offshore intake, but would be suitable for filters at the pumphouse.

Another approach to the backwash pump problem might be to commit a high capacity 6,200 gpm pump with separate water suction piping to a storage tank solely as a backwash pump and have two alternately used 140 square feet rapid sand filter beds.

A third approach to this intermittent backwash requirement is using an elevated storage tank, 26 feet above ground level, at the

building location. The tank capacity required would be equal to the backwash requirement (required gpm x backwash cycle duration) plus the volume of the backwash 14 inch pipe for the estimated 3,000 foot run from the storage tank to the filter bed. A portion of the chiller coil discharge would be pumped into the storage tank. This would present a freeze-up problem at the Corea site.

(3) Backwash Cycle Calculation

The backwashing interval for a rapid sand filter is dependent upon the filtration rate of the influent (2 gpm per square foot), the turbidity content of the influent (100 ppm), and the solids-holding capacity of the filter media (one lb. per square foot). The filtration rate of 2 gpm is used to determine the actual back-wash interval.[9]

s = pounds of solids per 1,000 gallons.

ppm = parts per million turbidity.

filter area = 140 sq. ft.

maximum holding capacity = 140 sq. ft. x 1 lb. per sq. ft. = 140 lb.

filtering capability = 140 sq. ft. x 2 gpm per sq. ft. = 280 gpm.

$$s = \frac{100 \text{ ppm}}{120}$$

$$s = \frac{100 \text{ ppm}}{120} \times \frac{280 \text{ gpm} \times 60 \text{ min.hr.}}{1{,}000 \text{ gal.}} = 14 \text{ PPH (pounds per hour)}$$

$$\text{backwashing interval} = \frac{140 \text{ lb. capacity}}{14 \text{ lb./hr.}} = 10 \text{ hr.}$$

INTERVAL BETWEEN BACKWASH AT A
FILTRATION PATE OF 280 GPM

Suspended Solids (dirt load) mg/l - ppm	Remarks	Backwash Interval Days	Hrs
3	open sea	13	21.3
15	good visibility	2	18.7
25		1	16
50	Penobscot Bay determination	0	20
100	max expected Prospect Harbor	0	10
500		0	2

(4) Chlorine Dosage Requirements in Backwash

The required dosage for each backwash cycle is dependent on the volume of water used in the cycle and the type of chlorine-producing compound used.

The volume required for one backwash cycle, or minimum storage tank holding capacity, should be greater than the combined volumes of the backwash (backwash rate x backwash interval), 14 in. backwash pipe (estimated 3000 ft. x pipe flow area), one half of the filtration pipe, and underdrain cavity.

Volume

backwash - 2,618 gpm x 5 min. = 13,090 gal. - 7.48 ft^3/gal	= 1,750 ft^3
backwash pipe - 14 in. pipe = .939 ft^2 x 3,000 ft.	= 2,817 ft^3
filtration pipe - 8 in. pipe = .347 ft^2 x 1,500 ft.	= 520 ft^3
filter cavity - 2 ft. x 140 ft^2	= 280 ft^3
	5,367 ft^3
Contingency + 10%	537 ft^3
	5,904 ft^3

$$5,904\ ft^3 \times 7.48\ gal/ft^3 = 44,162\ gal.$$

Noting the probable frequency of the backwash, the backwash volume, and considering the hazards involved with all chlorine compounds, the selection of the use of liquid chlorine seems indicated.

Assuming an average yearly influent suspended solids load of 50 ppm will require a backwash cycle every twenty hours, or 438 times a year. The quantity of chlorine gas required to chlorinate 44,162 gallons of H_2O to an initial 3 ppm strength is approximately .11 pounds of chlorine gas. One year's average backwash cycles, 438 times, would require approximately 48 pounds of chlorine. A standard 150 lb. bottle of chlorine should last three years. The initial cost of a bottle-mounted chlorinator, injector booster pump, injector access, bottle deposits, and chlorine is approximately $2,000. The price of bottled chlorine gas varied from 19 to 26 cents per pound depending on location.

As an alternative, a shock chlorination treatment of the filtration influent @ 280 gpm of 20 ppm for two hours, twice a day, for a total of four hours per day, requires 4,055 pounds of chlorine gas per year. The initial basic chlorination set-up costs of $2,000 would remain the same. The cost of the 4,055 lb. of chlorine @ $.26 per lb. = $1,038.

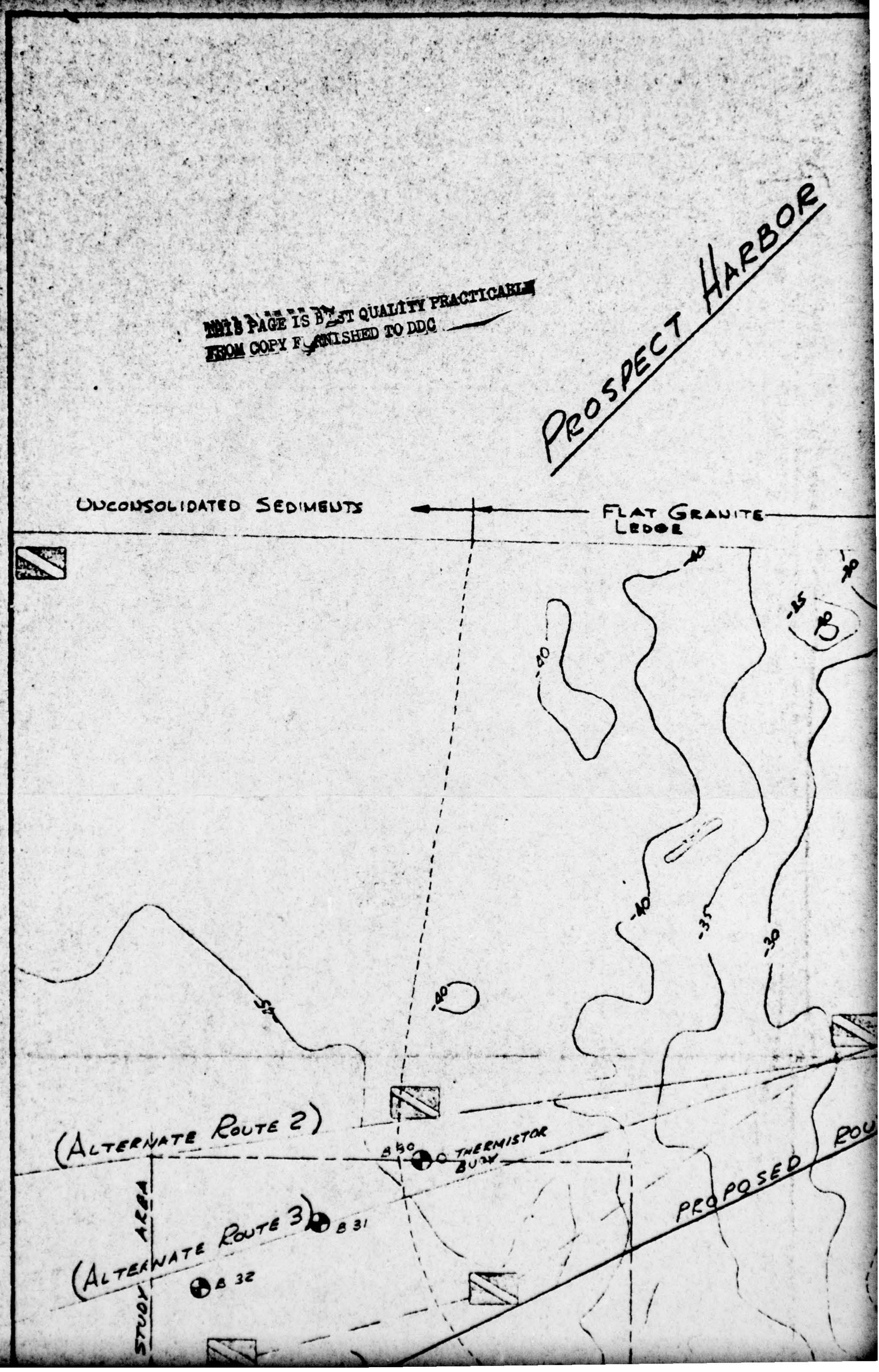
3. Other Mechanical Filters

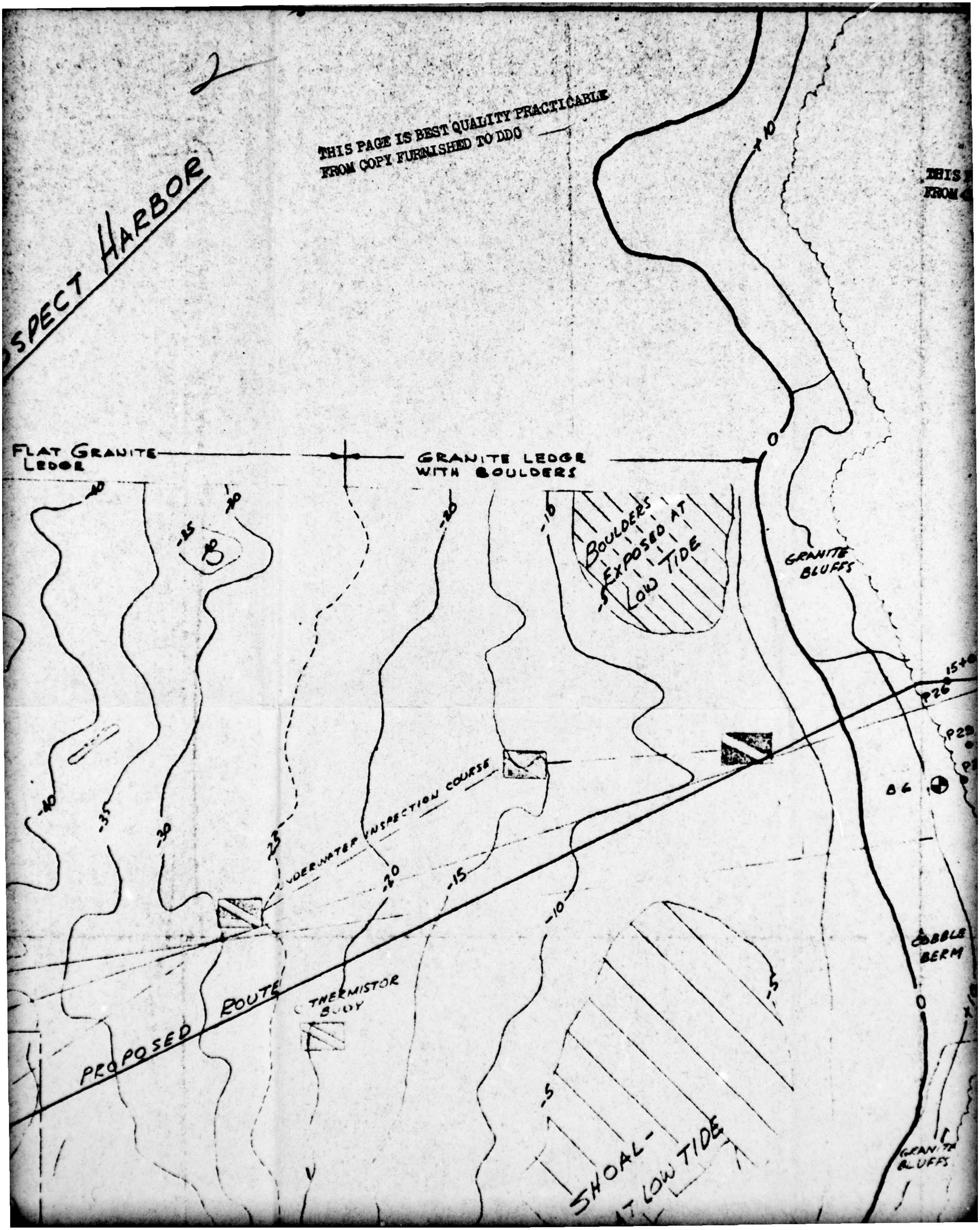
The mechanical filtration equipment, i.e., pressured conventional rapid sand filters, precoated pressure leaf and tubular diatomaceous earth filters, pressure high rate upflow filter, and cartridge filters are capable of filtering out suspended solid particles on the order of 15 microns and above. However, they all

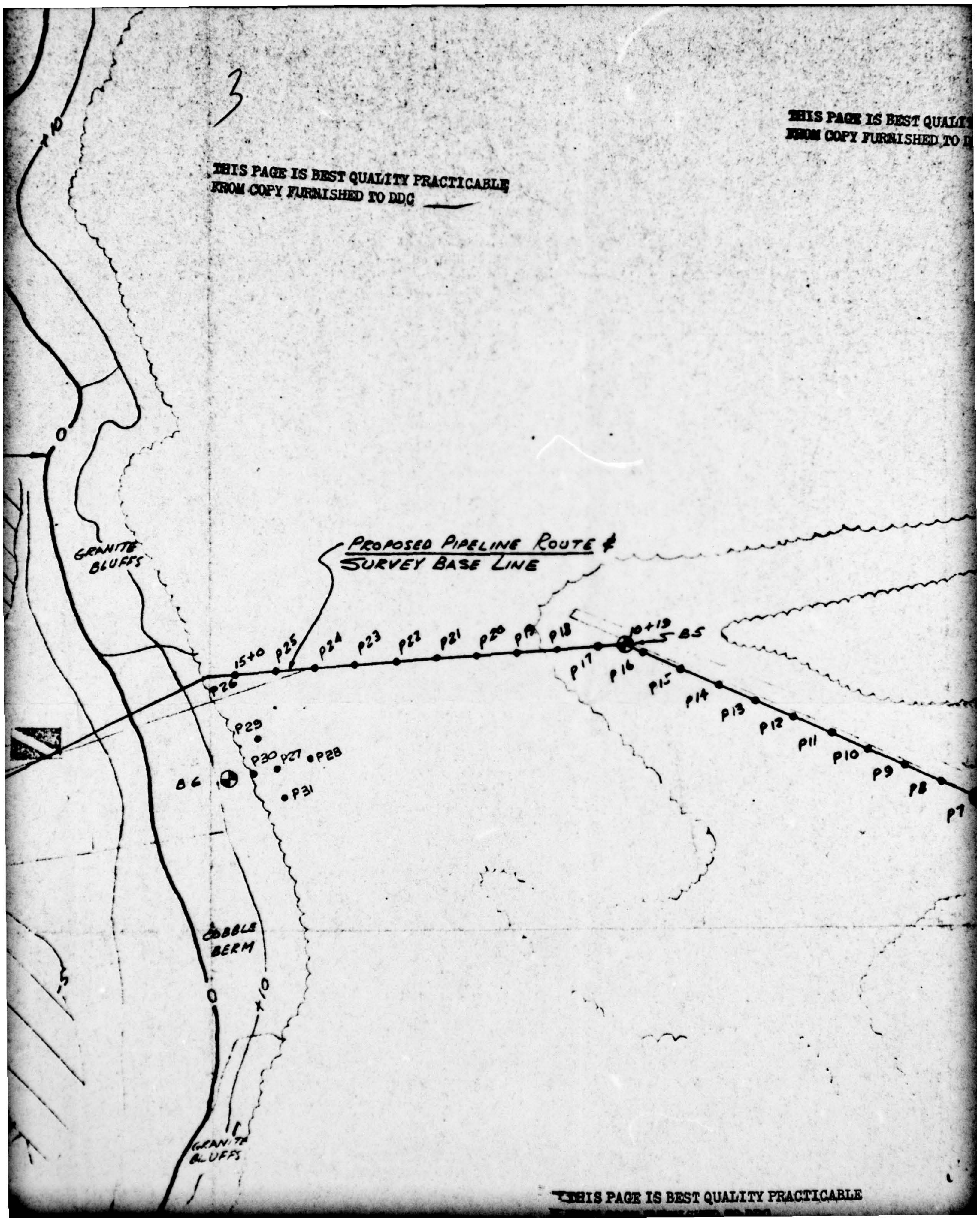
require a substantial pressure drop across the filter, even in the clean media condition, on the order of 5 psi or 11.6 feet of head. This head requirement would preclude their use on the suction side of a pumping system. The mechanical cyclonic filters available today are based on an operating principle of centrifugal force for suspended solids separation. This type of filter can operate effectively only if the suspended particles have a specific gravity on the order of 1.5, the marine animal life would have a specific gravity approaching 1.0; therefore, their use could be ineffective. The only other alternatives are a low pressure rapid sand filter, a slow sand filter, or a seawater well using natural sediments as a filter.

APPENDIX C

LOG OF SEDIMENT BORINGS AND LOCATION MAP


PROSPECT HARBOR
UNCONSOLIDATED SEDIMENTS
FLAT GRANITE LEDGE
-40
-35
-30
(ALTERNATE ROUTE 2)
B 30
THERMISTOR BUOY
(ALTERNATE ROUTE 3)
B 31
B 32
STUDY AREA
PROPOSED ROU


2
PROSPECT HARBOR
FLAT GRANITE LEDGE
GRANITE LEDGE WITH BOULDERS
BOULDERS EXPOSED AT LOW TIDE
GRANITE BLUFFS
UNDERWATER INSPECTION COURSE
THERMISTOR BUOY
PROPOSED ROUTE
SHOAL AT LOW TIDE
COBBLE BERM
GRANITE BLUFFS
15+0
P26
P25
B6



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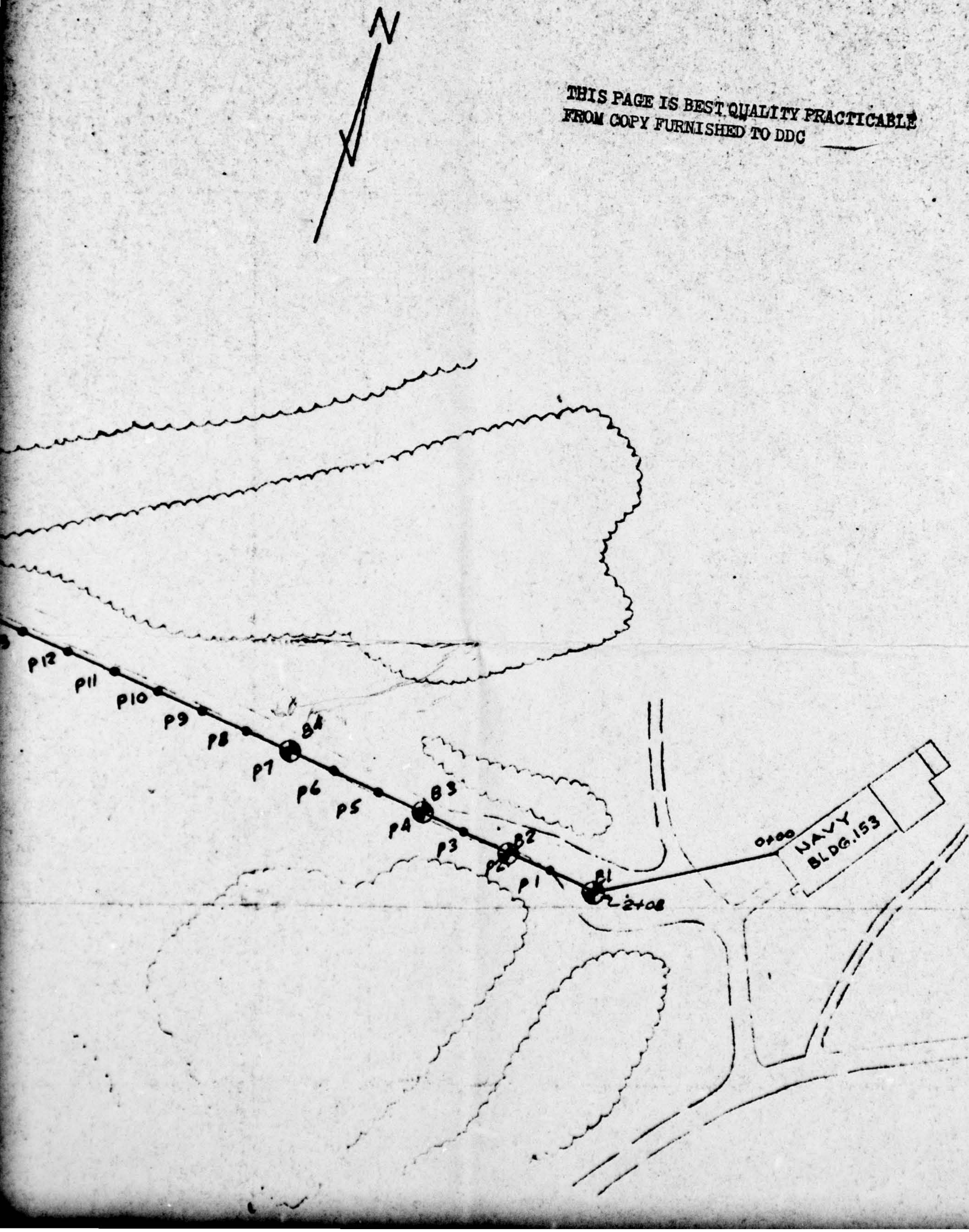

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engineers • planners • surveyors
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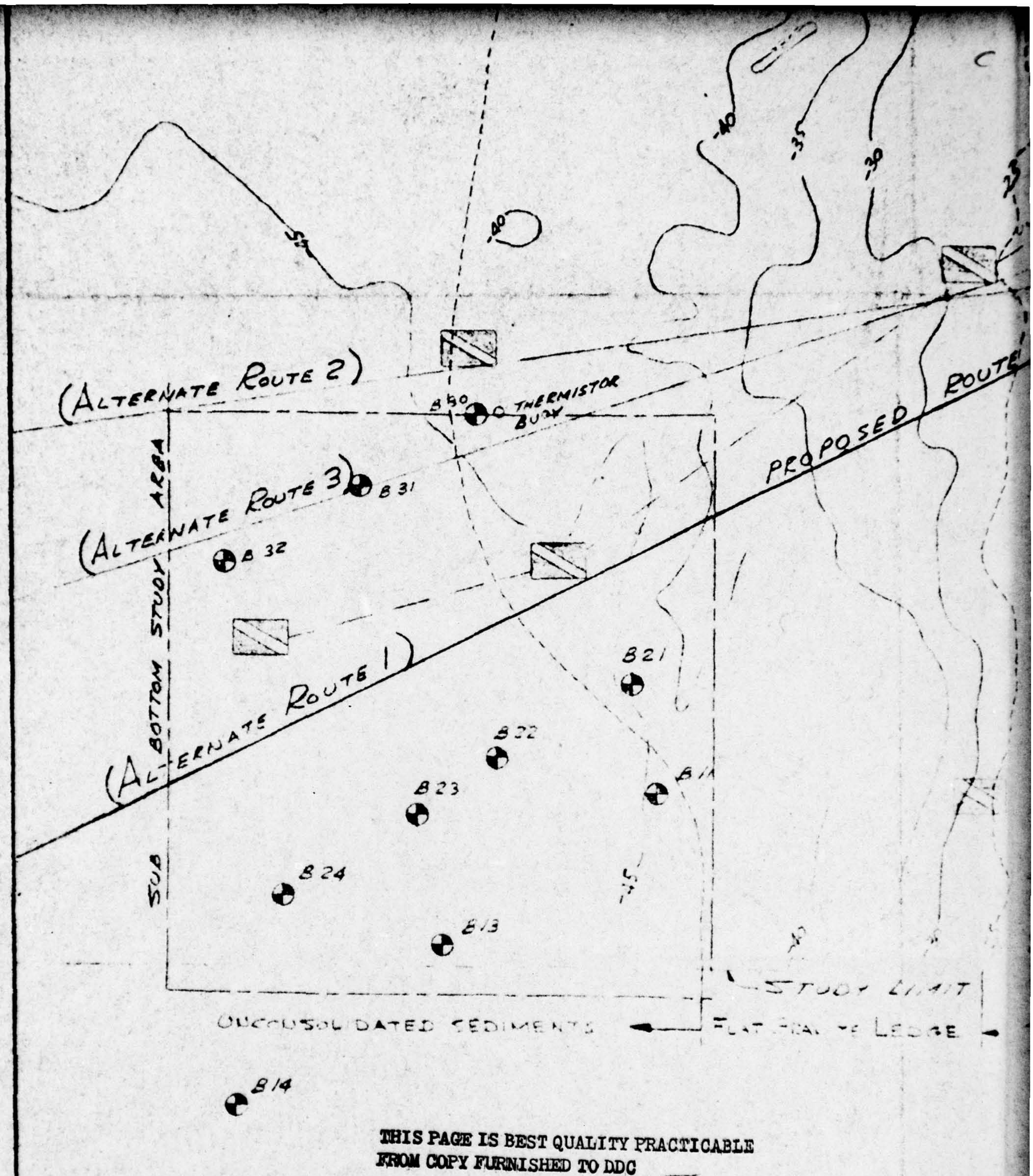
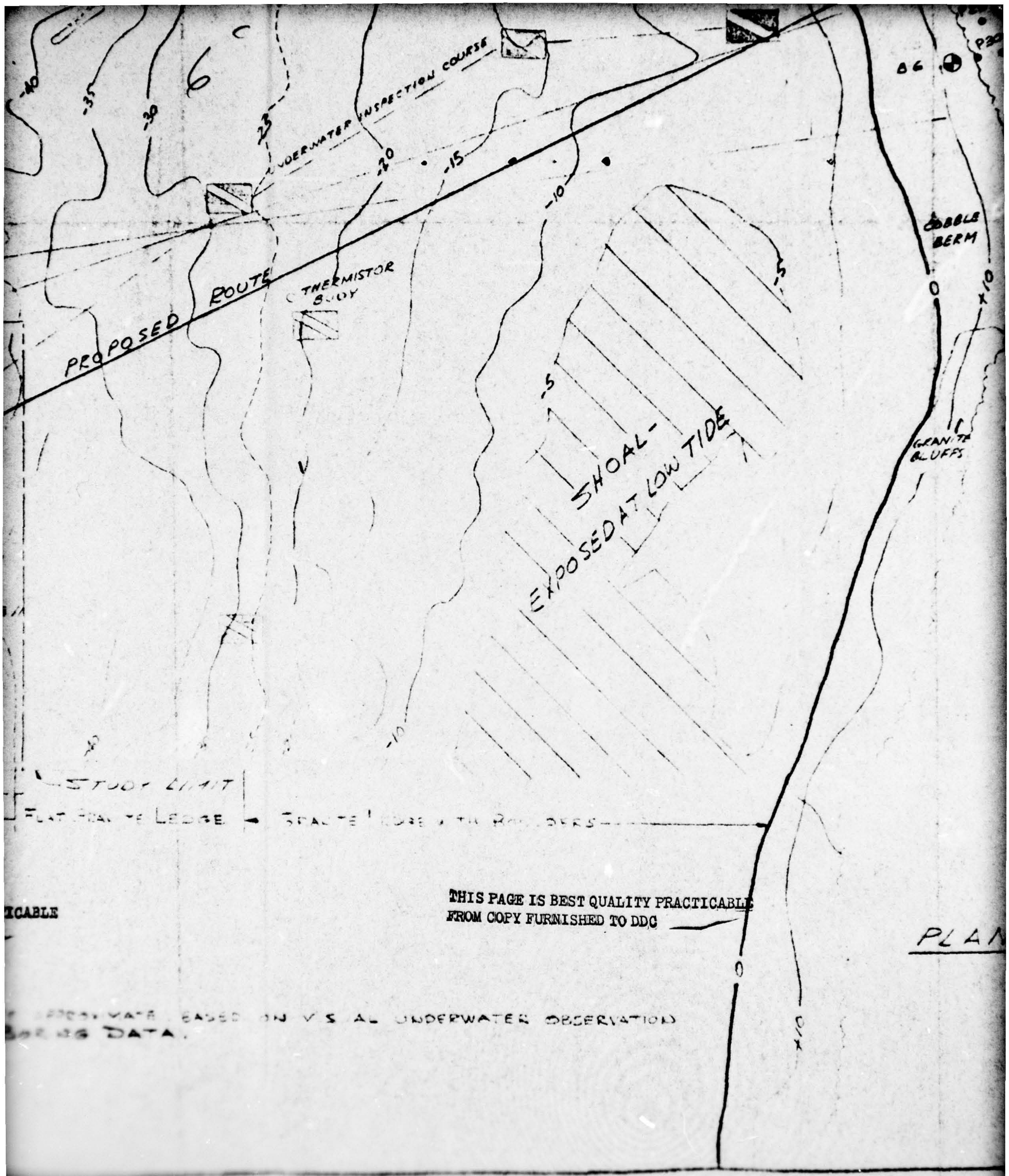
A, MAINE.

5



NOTE: LIMITS OF OFFSHORE GEOLOGY ARE APPROXIMATE, BASED ON
ALONG INDICATED AREAS AND ON BORING DATA.



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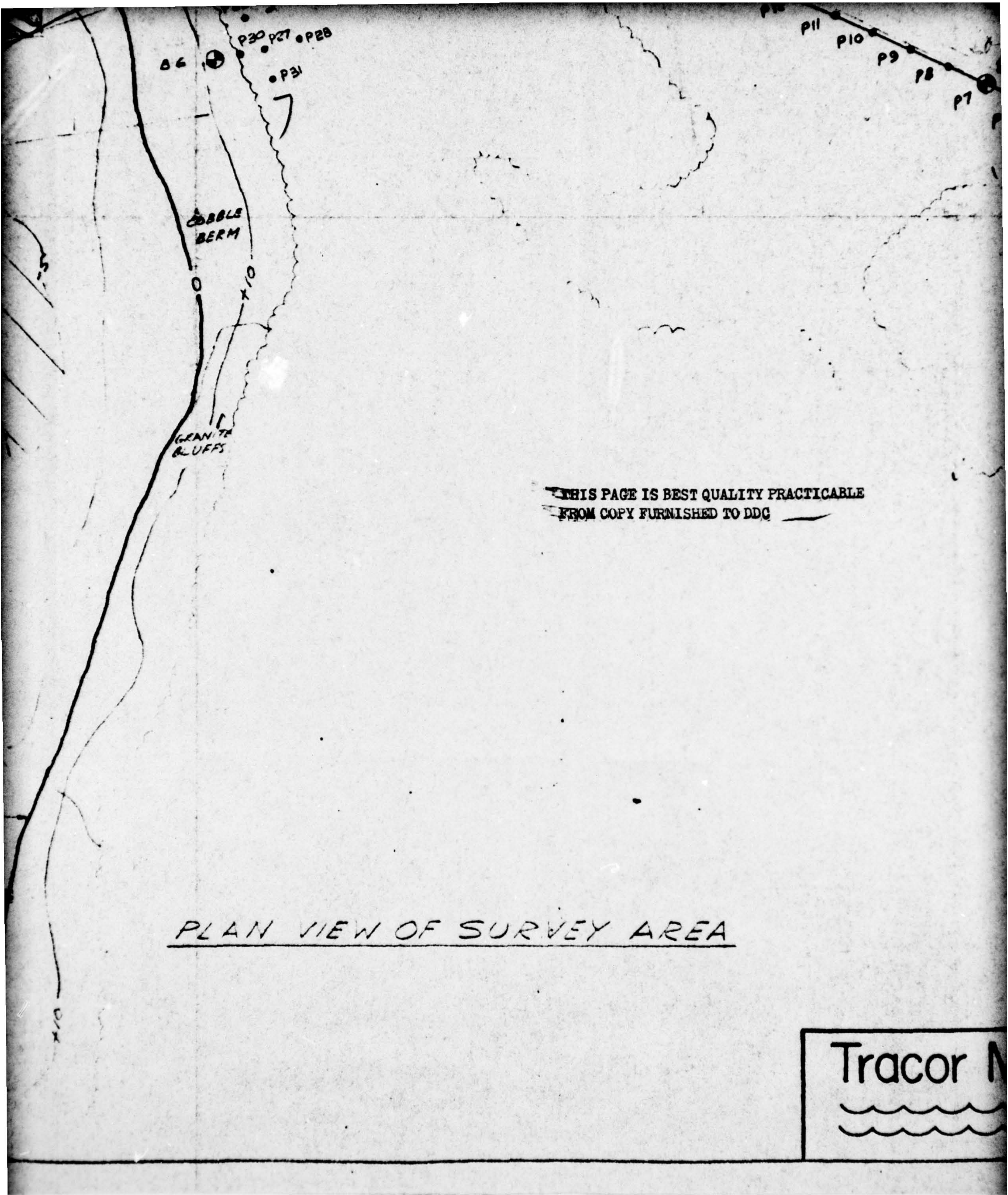

P30
P27
P28
P31
P11
P10
P9
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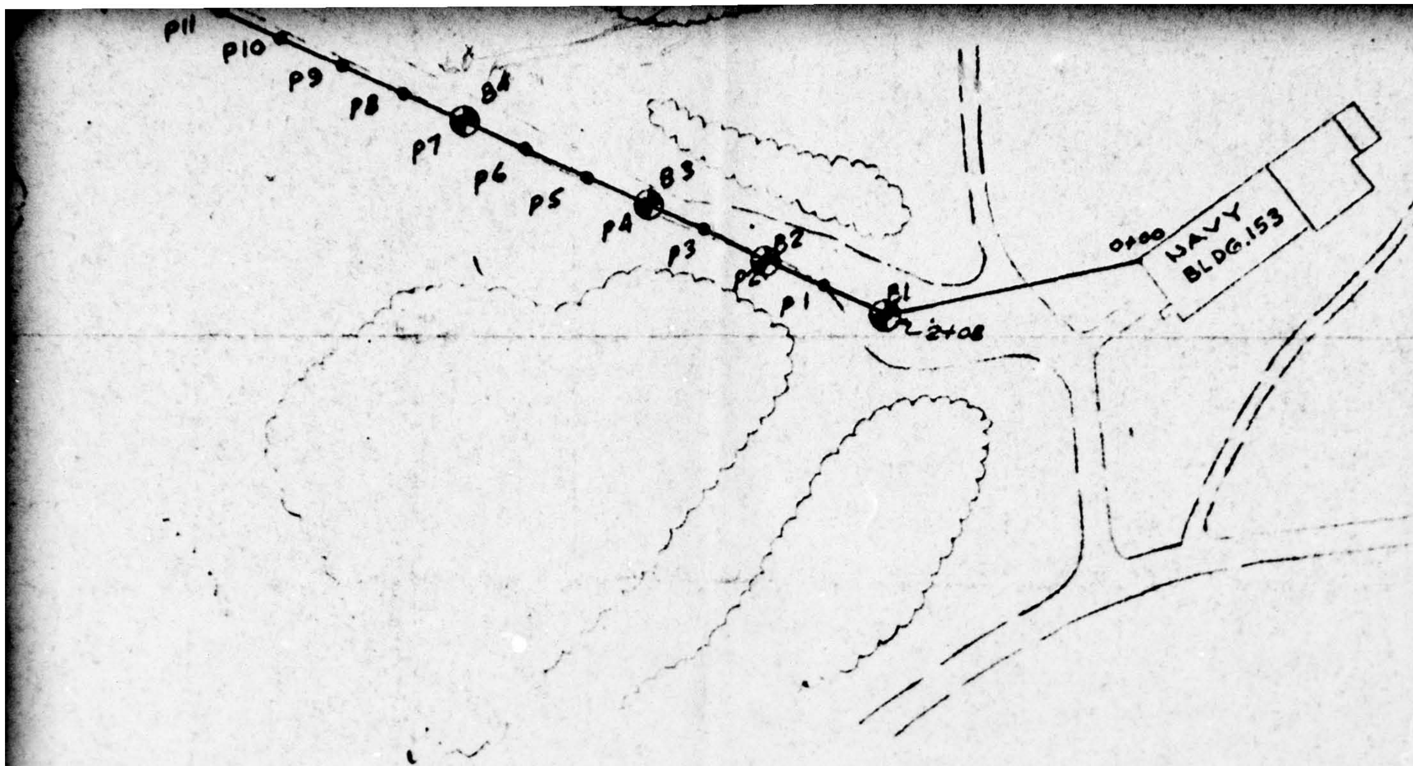
P7
COBBLE
BERM
GRANITE
BLUFFS
PLAN VIEW OF SURVEY AREA
Tracor



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SCALE: 1" = 100'

SHORE LINE DATUM - MEAN SEA LEVEL + 1.53 FT.

TREE LINES

Boring Locations - See Sheet No 10

• Probe Locations - See Sheet No 9

Sites of visual underwater inspection by divers. Connected flags indicate continuous underwater inspection

Tracor Marine
P.O. BOX 13114
PT. EVERGLADES, FLORIDA
33316

8

engineers

PROJECT: PIPELINE ROUTE SURVEY
U.S. NAVY SECURITY FACILITY
COREA, MAINE.

DRAWING NUMBER: 5192E-04-0036

DATE: NOV 11, 1977 FB ____ PP ____

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CHECKED BY: H. [illegible]

SHEET: 8-10

COMM NO: S192E

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UNCLASSIFIED TRACOR-726171-SUPPL CEL-CR-78.009 NL

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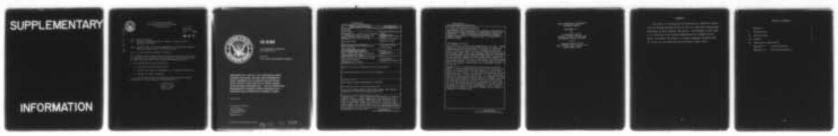

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SUPPLEMENTARY

INFORMATION

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JAN 15 79

From: Officer in Charge
To: Defense Documentation Center, Building 5, Cameron Station, Alexandria, VA 22314

Subj: Contract Report, CR 78.009, Supplements to Preliminary Design for Seawater Cooling Project, NSGA Winter Harbor

Encl: (1) Five Correction Sheets (12 copies)

1. The subject report, which contains some minor editorial errors, may be corrected by the substitution and inclusion of the pages of enclosure (1) into the twelve copies sent to Defense Documentation Center.

2. These substitutions and inclusions are:

a. replace the cover and DD Form 1473

b. add the title page for Supplement No. 1 following DD Form 1473

c. replace the Table of Contents

d. add the yellow sheet in between the figure entitled "Typical Installation" and the title page for Supplement No. 2.

Peter D. Triem
PETER D. TRIEM
By direction

CR 78.009

CIVIL ENGINEERING LABORATORY
Port Hueneme, California

Sponsored by

NAVAL FACILITIES ENGINEERING COMMAND

SUPPLEMENTS NO. 1 AND NO. 2 TO A PRELIMINARY DESIGN, ECONOMIC AND ENERGY ANALYSIS, AND ENVIRONMENTAL IMPACT ASSESSMENT FOR A SEAWATER COOLING PROJECT, NAVAL SECURITY GROUP FACILITIES AT WINTER HARBOR, MAINE (CR 78.008), SUPPLEMENT NO. 1: BOTTOM TEMPERATURE MEASUREMENTS IN PROSPECT HARBOR, SUPPLEMENT NO. 2: BIOFOULING AND ITS PREVENTION IN PROSPECT HARBOR

November 1977

An Investigation Conducted by

TRACOR MARINE
Ocean Technology Division
Port Everglades, Florida

N68305-77-C-0012

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: CR 78.009
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): SUPPLEMENTS NO. 1 AND NO. 2 TO CR78.008 (A PRELIMINARY DESIGN, ECONOMIC AND ENERGY ANALYSIS AND (continued)
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6. PERFORMING ORG. REPORT NUMBER: 726171
7. AUTHOR(s): Jules Hirschman
8. CONTRACT OR GRANT NUMBER(s): N68305-77-C-0012
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Tracor Marine, Ocean Technology Div. P.O. Box 13114 Port Everglades, FL 33316
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Z0412-01-001
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12. REPORT DATE: November 1977
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15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This report contains supplements to CR78.008.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Air conditioning; seawater; NSGA Winter Harbor, ME; seawater temperature; biofouling; Prospect Harbor, ME

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Supplement No. 1 - Bottom Temperature Measurements in Prospect Harbor: Maximum seawater temperatures were measured on the bottom of Prospect Harbor which adjoins the Corea, ME, detachment of NSGA Winter Harbor, ME, from July to October at two water depths. At a water depth of 45 feet the average temperature reached 50°F near the end of July and remained (continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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(4) Title (and Subtitle) Continued

ENVIRONMENTAL IMPACT ASSESSMENT FOR A SEAWATER COOLING PROJECT, NAVAL SECURITY GROUP FACILITIES AT WINTER HARBOR, MAINE; SUPPLEMENT NO. 1: BOTTOM TEMPERATURE MEASUREMENTS IN PROSPECT HARBOR; SUPPLEMENT NO. 2: BIOFOULING AND ITS PREVENTION IN PROSPECT HARBOR

(20) Abstract Continued

above 50°F until the end of the measurements in October. Higher temperature transients exceeding 53°F occurred in August and early September for several hours; the highest of these was 55.8°F. At a water depth of 20 feet the temperatures were several degrees higher until early September, when the temperatures at the shallower location closely followed those of the deeper. It was concluded regarding the NSGA Winter Harbor seawater air conditioning (AC) system that (1) enhancement is required during the hottest weather, (2) reduction in the heat gain is desirable and (3) the seawater intake should be at the deeper location (45-50 feet).

Supplement No. 2 - Biofouling and Its Prevention in Prospect Harbor: A detailed examination was made of the biofouling community in Prospect Harbor, the NSGA seawater AC system components which are sensitive to biofouling, and biofouling countermeasure systems. It was concluded that: (1) this system must cope with a serious biofouling problem, (2) a seawater well sunk into the bottom sediments could be used as the seawater intake and would provide the most suitable solution to this problem, (3) sufficient sediment thickness is available for such a well but it is not certain whether the sediments in the intake area can support the required flow (permeability), and (4) copper-nickel alloy tubing or ultraviolet treatment may be required to supplement the seawater well.

BOTTOM TEMPERATURE MEASUREMENTS
IN PROSPECT HARBOR

SUPPLEMENT NO. 1

TO

A PRELIMINARY DESIGN,
ECONOMIC & ENERGY ANALYSIS, AND
ENVIRONMENTAL IMPACT ASSESSMENT

FOR A

SEAWATER COOLING PROJECT
NAVAL SECURITY GROUP FACILITIES IN
WINTER HARBOR, MAINE

FOREWORD

This work is a continuation of Contract No. N68305-77-C-0012 with the Energy Programs Office of the U.S. Navy Civil Engineering Laboratory in Port Hueneme, California. The purpose of this work is to determine actual bottom temperatures in Prospect Harbor, Maine, to support the design of a direct seawater building cooling system at the Naval Security Facility, Corea, Maine.

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